Beyond mere take-over requests: The effects of monitoring requests on driver attention, take-over performance, and acceptance

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Beyond Mere Take-Over Requests: The Effects of Monitoring Requests on Driver Attention, Take-Over Performance, and Acceptance

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Abstract

In conditionally automated driving, drivers do not have to monitor the road, whereas in partially automated driving, drivers have to monitor the road permanently. We evaluated a dynamic allocation of monitoring tasks to human and automation by providing a monitoring request (MR) before a possible take-over request (TOR), with the aim to better prepare drivers to take over safely and efficiently. In a simulator-based study, an MR+TOR condition was compared with a TOR-only condition using a within-subject design with 41 participants. In the MR+TOR condition, an MR was triggered 12 s before a zebra crossing, and a TOR was provided 7 s after the MR onset if pedestrians crossing the road were detected. In the TOR-only condition, a TOR was provided 5 s before the vehicle would collide with a pedestrian if the participant did not intervene. Participants were instructed to perform a self-paced visual-motor non-driving task during automated driving. Eye tracking results showed that participants in the MR+TOR condition responded to the MR by looking at the driving environment. They also exhibited better take-over performance, with a shorter response time to the TOR and a longer minimum time to collision as compared to the TOR-only condition. Subjective evaluations also showed advantages of the MR: participants reported lower workload, higher acceptance, and higher trust in the MR+TOR condition as compared to the TOR-only condition.

Participants' reliance on automation was tested in a third drive (MR-only condition), where automation failed to provide a TOR after an MR. The MR-only condition resulted in later responses (and errors of omission) as compared to the MR+TOR condition. It is concluded that MRs have the potential to increase safety and acceptance of automated driving as compared to systems only providing TORs. Drivers' trust calibration and reliance on automation will need further investigation.

1. Introduction

1.1. Level 2 and 3 Automated Driving

Automated driving is gradually being introduced to the market and may bring benefits to traffic safety, travel comfort, traffic flow, and energy consumption (Fagnant & Kockelman, 2015; Kühn & Hannawald, 2014; Kyriakidis, Happee, & De Winter, 2015; Meyer & Deix, 2014; Watzenig & Horn, 2017). A number of car manufacturers have released partially automated driving technology (Level 2 automation as defined by SAE International, 2016), combining adaptive cruise control with a lane keeping system. Partially automated driving still requires the driver to monitor the road and be able to take immediate control at all times. Manufacturers and scientists are now working towards a higher level of automation (i.e., SAE Level 3 'conditional automation') in which the system is capable of driving in certain conditions and the driver does not have to monitor the road anymore. In case the system reaches its operational limits, the driver has to take control in response to a take-over request (TOR).

1.2. The Demanding Time Budgets of Take-Over requests

When taking over control, drivers need time to acquire situation awareness (Lu, Coster, & De Winter, 2017; Samuel, Borowsky, Zilberstein, & Fisher, 2016) and physically prepare for taking over control (Large, Burnett, Morris, Muthumani, & Matthias, 2017; Zeeb, Härtel, Buchner, & Schrauf, 2017; Zhang, Wilschut, Willemsen, & Martens, 2017). A large body of research has confirmed the importance of the time budget, defined as the available time between the TOR and colliding with an obstacle or crossing a safety boundary (see Eriksson & Stanton, 2017; Zhang, De Winter, Varotto, Happee & Martens, 2018, for reviews). While time budgets between 5 and 7 s are often used (Zhang et al., 2018), how much time drivers need for taking over control may depend on the driving task and context. Mok, Johns, Miller, and Ju (2017) showed that almost all drivers crashed when the time budget was only 2 s, whereas Lu et al. (2017) showed improvements in situation awareness up to 20 seconds of preparation time.

In on-road settings, a TOR with a long time budget cannot always be provided. If the automation relies on radars or cameras to detect a collision with other road users, the achievable time budget of the TOR depends on the predictability of the unfolding situation and the capabilities of the sensors, which implies that the time budget between the TOR and the collision is usually short. In a review about human-machine interfaces in automated driving, Carsten and Martens (2018) explained that it is often unfeasible for the automated driving system to indicate in sufficient time that human intervention will be needed, which "necessitates constant monitoring by the human, so that a system that is supposed to be relaxing may actually be quite demanding".

1.3. Monitoring Requests and Uncertainty Presentation

In a review on transitions in automated driving from a human factors perspective (Lu, Happee, Cabrall, Kyriakidis, & De Winter, 2016), transitions in automated driving were classified into two types: control transitions and monitoring transitions. Lu et al. (2016) argued that much of the human factors literature has focused on control transitions (e.g., studies of take-over time), and pointed out that the two transition types can occur independently. For example, the driver may decide to monitor the road and achieve situation awareness, without necessarily taking over control.

Gold, Lorenz, Damböck, and Bengler (2013) previously implemented the concept of monitoring requests (MRs) in a driving simulator with the aim to achieve a monitoring transition that prepares drivers for a possible TOR. In their study, a TOR was provided if an uncertain situation became critical (i.e., a pedestrian or object entering the lane of the ego vehicle). The participants were instructed to monitor with their eyes only or with their hands on the wheel in addition. Results showed shorter take-over times and fewer cases of no intervention when the participants were monitoring 'hands on' as compared to visual-only monitoring. By comparing to one of their previous studies (Gold, Damböck, Lorenz, and Bengler, 2013), the authors suggested that the MR concept is effective in terms of safety. Louw et al. (2017a, 2017b) applied a concept in which an uncertainty alert was implemented upon the detection of a lead vehicle. The lead vehicle could decelerate, accelerate, or change lanes, and participants had to decide themselves whether to take over, as no TOR was provided. The study by Louw et al. examined relationships between drivers' eye movement patterns and crashes outcomes. However, an evaluation of the uncertainty alarm was not within their research scope. Summarizing, based on the above studies, it seems that the provision of MRs is viable in automated driving. However, the above studies did not directly compare the effects of the MR concept with a system that provides only a TOR. It would be relevant to make such a comparison and examine whether MRs prepare drivers to take over control safely in response to a subsequent TOR.

Herein, we evaluated a concept where, in addition to issuing a TOR, we provided an MR when approaching a critical location. Such an MR concept would rely not on camera/radar/lidar, but on basic localization (e.g., differential GPS, HD maps). That is, the MR could be applied when approaching a segment of the road where TORs are likely to occur (e.g., an intersection, zebra crossing, or construction works). The automation system thus degrades itself from Level 3 to Level 2 by promoting a temporary monitoring transition when it is uncertain of the (upcoming) environment, instead of changing from Level 3 to manual driving directly. The idea of an MR is that a driver is primed to take-over control but does not necessarily have to take over control.

In the literature, several concepts exist that are similar to MRs. Outside of the domain of driving, likelihood alarm systems (LAS) have been devised, which issue different types of notifications depending on the likelihood that a critical event occurs (e.g., Balaud, 2015; Wiczorek, Balaud & Manzey, 2015). Also in driving research, concepts have been designed that intermittently or continuously inform the driver and accordingly ensure that drivers are prepared to reclaim manual control. For example, in a driving simulator study, Beller, Heesen, and Vollrath (2013) presented an uncertainty symbol in unclear situations (when the front vehicle was driving in the middle of the two lanes). No TOR was available and the participants had to decide themselves whether to intervene or not. Compared to without such an uncertainty symbol, the participants intervened with a longer time to collision (TTC) in case of automation failure. Other examples are a LED bar on the instrument cluster indicating the momentary abilities of the automation (Helldin, Falkman, Riveiro, & Davidsson, 2013; Large et al., 2017), an ambient LED strip changing its colour or blinking patterns based on hazard uncertainty information (Dziennus, Kelsch, & Schieben, 2016; Yang et al., 2017), a continuous verbal notification informing the driver about the state of the ego car and the behaviour of other road users (Cohen-Lazry, Borowsky, & Oron-Gilad, 2017), and a lane-line tracking confidence notification (Tijerina et al., 2017). The results of these studies showed that participants who were provided with the uncertainty indication were better prepared in critical situations (Dziennus et al., 2016; Helldin et al., 2013; Yang et al., 2017).

However, there are also a number of potential shortcomings of uncertainty presentations. In particular, continuous displays require driver attention and may hinder engagement in non-driving tasks. Conversely, drivers may neglect such displays when they wish to perform a non-driving task (Cohen-Lazry et al., 2017; Yang et al., 2017).

Finally, it is noted that a number of studies have used the concept of “soft-TOR” or “two-step TOR” to acquire the driver’s attention before taking over control (Lapoehn et al., 2016; Naujoks, Purucker, Neukum, Wolter, & Steiger, 2015; Van den Beukel, van der Voort, & Eger, 2016; Willemsen, Stuiver, & Hogema, 2015; and see Brandenburg & Epple, 2018 for a questionnaire study). Two-step TORs differ from MRs because with a two-step TOR, the driver always has to take over after receiving the notification, whereas this is not necessarily the case with the MR concept.

1.4. Reliance Effects

Tijerina et al. (2017) showed that a ‘cry wolf’ effect occurs if the uncertainty notification was issued frequently without an actual need for a response. Similarly, a study evaluating the effects of advisory warning systems in automated driving showed that false alarms caused a cry-wolf effect (Naujoks, Kiesel, and Neukum (2016). In the cry-wolf effect, Type I errors (false alarms) cause a reduction in reliance. The opposite effect is also possible: if warnings unfailingly require a response, the operator may develop (over)reliance on those warnings, which can be manifested by so-called errors of omission (i.e., not responding when there is no warning) or errors of commission (i.e., complacently responding to a warning that is inappropriate in the given context) (Skitka, Mosier, & Burdick, 1999). Accordingly, it can be argued that any study on in-vehicle warnings ought to include an evaluation of drivers’ reliance and trust. In the present study, we examined whether drivers over-relied on the TOR, despite the fact that they were being forewarned by means of an MR.

1.5. Aim of the Study

In summary, the concepts of uncertainty presentation and MRs are promising, as they can increase situation awareness and cognitively and physically prepare drivers to intervene when needed. However, the literature also points to potential risks in terms of distraction. At present, it is unknown whether an MR works as intended by priming drivers to take-over control if needed. A successful MR system should ensure that drivers respond quickly to a subsequent TOR, and ensure that drivers do not take over if no critical event occurs. Furthermore, it is unknown whether drivers would accept a concept that intermittently requests them to monitor the road.

In this study, a system was implemented that intends to direct the driver's attention to the road by means of an MR when the automation enters a location where a take-over is likely to occur (i.e., a zebra crossing, where pedestrians could sometimes cross the road). The driver's monitoring state (i.e., whether the driver responded by attending to the road and touching the steering wheel), driving performance (braking and steering behaviour in response to a TOR presented after the MR), as well as subjective experience (a variety of human constructs such as workload and trust, Parasuraman, Sheridan, & Wickens, 2008) using such an MR+TOR system were compared with a baseline system which presented only a TOR. Accordingly, the aim of this study was to investigate whether drivers are responsive to the MR by looking at the road when requested, whether drivers do not unnecessarily take over control when no action is needed (when no pedestrians cross the road), and whether drivers have a shorter take-over time when being forewarned by the MR as compared to when receiving only a TOR.

An additional aim of this study was to examine whether drivers' exhibited overreliance on the TORs. An on-road study by Victor et al., (2018) suggests that drivers may fail to act despite being alerted and having their eyes on the road. Thus, there is a certain risk that drivers may not act in a critical situation when the system fails to provide a TOR, despite the fact that an MR is presented beforehand. To evaluate this risk, we included a final trial where an MR was presented, but no TOR followed. This scenario is realistic: As explained above, in some cases, the sensors of the automated driving system may not detect the hazard, and no TOR can be provided. Accordingly, we examined whether drivers failed to respond to a hazard (i.e., an error of omission) in an MR-only scenario in comparison to an MR+TOR scenario.

2. Methods

2.1. Participants

Forty-one participants (35 males, 6 females) were recruited through Facebook and University whiteboard advertisements. Their mean age was 29.6 years (*SD* = 7.0, ranging from 20 to 57 years). All participants had a valid driving license (which was held for 11.2 years on average, *SD* = 7.2). Participants were compensated with 10 euros.

Of the 41 participants, 4 participants had experience with driving in a simulator prior to this study. Furthermore, 18, 12, and 6 participants reported prior experience with adaptive cruise control, a lane keeping system, and partially automated driving, respectively. All participants provided written informed consent, and the research was approved by the Human Research Ethics Committee (HREC) of the Delft University of Technology.

2.2. Apparatus

The study was conducted in a static driving simulator located at the Technical University of Munich, Germany. The simulator consists of a BMW 6-Series vehicle mock-up, and provides an approximately 180 degrees field of view. Three projectors provided views for the rear-view mirrors. The software for simulating the driving scenarios was SILAB from WIVW GmbH, which recorded the vehicle data at a frequency of 120 Hz. The automated driving system controlled longitudinal and lateral motion, and could be activated and deactivated by pressing a button on the steering wheel. The sound effects of the engine, passing vehicles, as well as warnings were provided via speakers of the vehicle cabin. A dashboard-mounted eye tracking system (Smart Eye) was used to record participants' eye movement at a frequency of 60 Hz. The driver's glance locations were classified into the following areas of interest (AOI): windshield (road in front of the driver), central console, left and right exterior mirror, rear-mirror, and instrument cluster. A 9.5 by 7.31-inch handheld tablet (iPad 2) was provided to the participants for performing a non-driving task. The vehicle and the cabin are shown in Figure 1.

Figure 1. The TU Munich Driving Simulator. Left: full-vehicle mock-up; Right: cabin.

2.3. Automation system and human-machine interface

In the basis of the experiment, two automation systems were tested: (1) MR+TOR: automation with take-over requests (TOR) being preceded by monitoring requests (MR) and (2) TOR-only: automation with TOR but without MR. The third condition (MR-only) was presented last to investigate whether the participants had developed overreliance on the TOR signal. This condition was analysed separately.

The MR+TOR system consisted of five automation states, with corresponding status icons shown on the dashboard (Figures 2 & 3). When the automation is unavailable, a white car on a light blue road is shown in the top center (Figure 2a) and the driver needs to drive manually. When the requirements for automated driving are fulfilled, a verbal notification “Automation available” was issued, and a green steering wheel icon was shown (Figure 2b). The driver could press a button on the steering wheel to activate the automation (the icon then changed to Figure 2c with an acoustic state-changing sound, i.e., a gong). When the automation was active, the participant could take the hands off the wheel and feet off the pedals.

When entering an area in which a critical situation might occur, the system issued an MR. The MR consisted of a verbal notification “Please monitor” following a gong sound, and a yellow eye-shaped icon (Figure 2d). The automation remained fully functional after the MR onset. If no critical event occurred, the MR was dismissed after passing the zebra crossing, and the icon changed back to the ‘automation activated’ state (Figure 2c) accompanied by a gong sound.

If the system detected a situation that it could not handle, a TOR was provided, and the automation was deactivated at the same time, leading to a slight deceleration. The acoustic TOR warning was a sharp double beep (75 dB, 2800 Hz) followed by a verbal take-over request “Please take-over”. Figure 2e and Figure 3 (right) show the visual display for the TOR: an orange hands-on-the-wheel icon in the lower center of the dashboard, and the automation state icon back to “automation unavailable” (Figure 2a). Upon receiving the TOR, the driver had to take over by steering and/or braking in response to the situation. After taking over control, the driver had to drive manually until the automation became available again; they could then reactivate the automation. The TOR-only system was identical to the MR+TOR system, except that there was no MR. In addition, the participants drove a third condition (MR-only), in which an MR but no TOR was provided before a critical event.

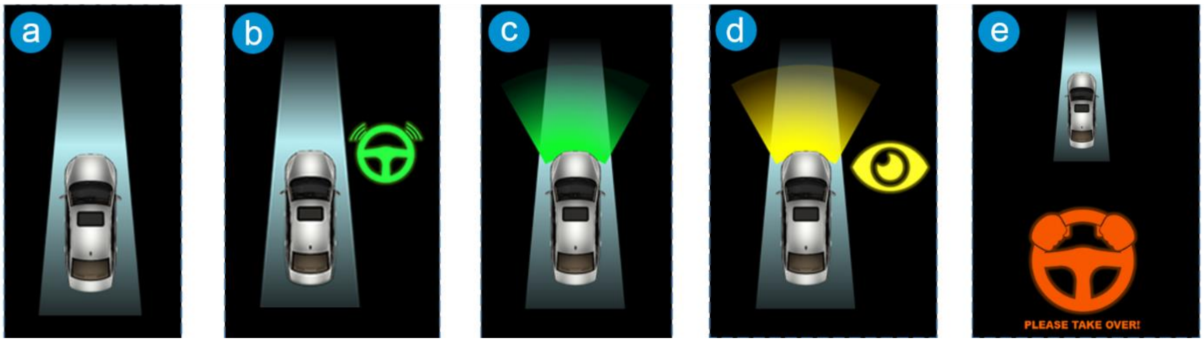


Figure 2. Screenshots of the visual interface for the five system states. a) automation unavailable; b) automation available but not yet activated; c) automation activated; d) monitoring request; e) take-over request.

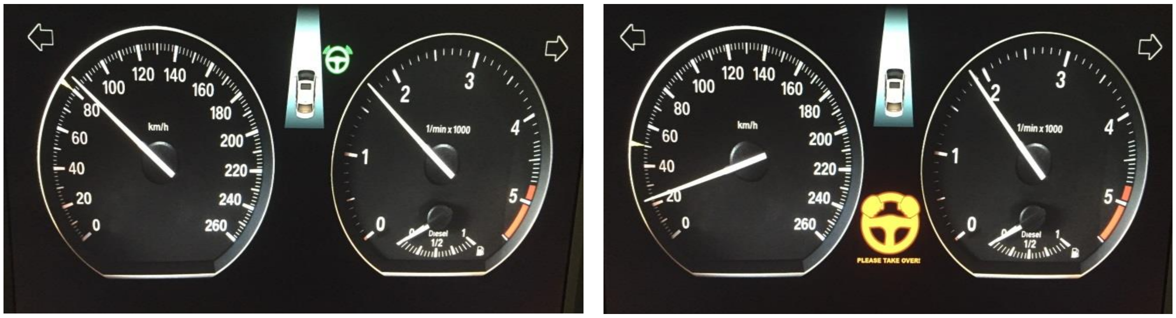


Figure 3. Photos of the instrument cluster with automation status. Left: automation available, corresponding to Figure 2b; Right: take-over request, corresponding to Figure 2e.

2.4. Experimental design and test scenarios

A within-subject design was used, meaning that each participant completed all three conditions (MR+TOR, TOR-only, MR-only) in three separate sessions. The MR+TOR and TOR-only conditions were counterbalanced, whereas the MR-only condition was always presented in the last (i.e., third) session.

The simulated experimental track consisted of rural and city road segments with one lane in each direction. There was moderate traffic in the opposite direction and no traffic in the ego lane. The speed limit was 80 km/h on the rural road and 50 km/h in the city, as indicated by speed limit signs along the road. The automation drove at a constant speed of 80 and 50 km/h in the corresponding segments (except for the deceleration and acceleration between the city and rural roads).

The critical events that required driver intervention were pedestrians who were crossing at a zebra crossing in the city road segments. Due to the layout and kinematics of the situation, braking was the required and expected action to avoid a collision, although some optional steering could be applied as well. The participants were not informed about the specific situation, and were told to respond by either steering or braking depending on their judgement. In the MR+TOR condition as well as the TOR-only condition, five zebra crossings were included. At two out of five crossings, two pedestrians stood behind an obstacle (either a bus stop or a truck) on the pavement, 1.5 m from being visible to the participant in the walking direction. The first crossing pedestrian started walking at a speed of 1.5 m/s when the participant's car was 83.33 m away from the zebra crossings (TTC = 6 s at 50 km/h). The other pedestrian crossed the road with a speed of 1 m/s, following the first pedestrian (Figure 4 Left). It took around 5 s for the first pedestrian and 9 s for the second pedestrian to cross the road. No pedestrians were present at the other three crossings, and the participants were not supposed to take over.

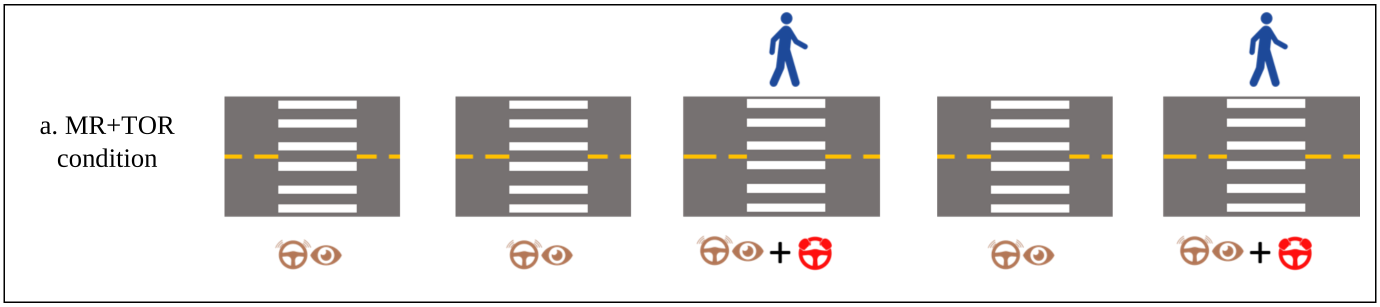
The TOR was provided at the moment the first pedestrian became visible on the edge of the side walk. The automation was deactivated together with the presentation of the TOR, which led to a slight deceleration of the vehicle if the drivers did not intervene. Based on pilot studies and the available literature, we opted for a time budget of 5 s; thus, the car would crash into the pedestrians in 5 s if the participant did not intervene. This time budget was expected to be mentally demanding, but should not result in a high number of collisions with the pedestrians (collisions would have been undesirable due to ethical reasons). A recent meta-analysis by Zhang et al. (2018) found that about 70% of the time budgets used in the experimental literature are between 5 and 7 s. From a study of Lu et al (2017), we reasoned that 7 s is sufficient for regaining situation awareness in a simple traffic scenario, whereas according to Gold, Damböck, Lorenz, and Bengler (2013), 5 s would be a challenging, yet manageable, time budget for visually distracted drivers to take back control.

In the MR+TOR condition, an MR was issued 12 s (166.67 m) before reaching the zebra crossing (i.e., the TOR was provided 7 s after the MR onset). The MR was deactivated when passing the zebra crossing without pedestrians

(Figure 4 Right). In each of the two conditions, the sequence of the five zebra crossings was randomized. The duration of each session was approximately 14 min.

The MR-only condition contained three zebra crossings. There were no pedestrians at the first two crossings. At the last crossing, two pedestrians started crossing the road 7 s after the MR was announced, but no TOR was given. This session ended after the critical event. The session of the MR-only condition lasted approximately 10 min. Figure 5 provides an illustration of the order of sessions and events for one participant.

Figure 4. Left: Zebra crossing with two pedestrians crossing the road (a take-over scenario). Right: Zebra crossing without pedestrians (here, it was not necessary to intervene). Note that these screenshots were taken from an observer’s perspective in the simulator software, not from the driver’s perspective.



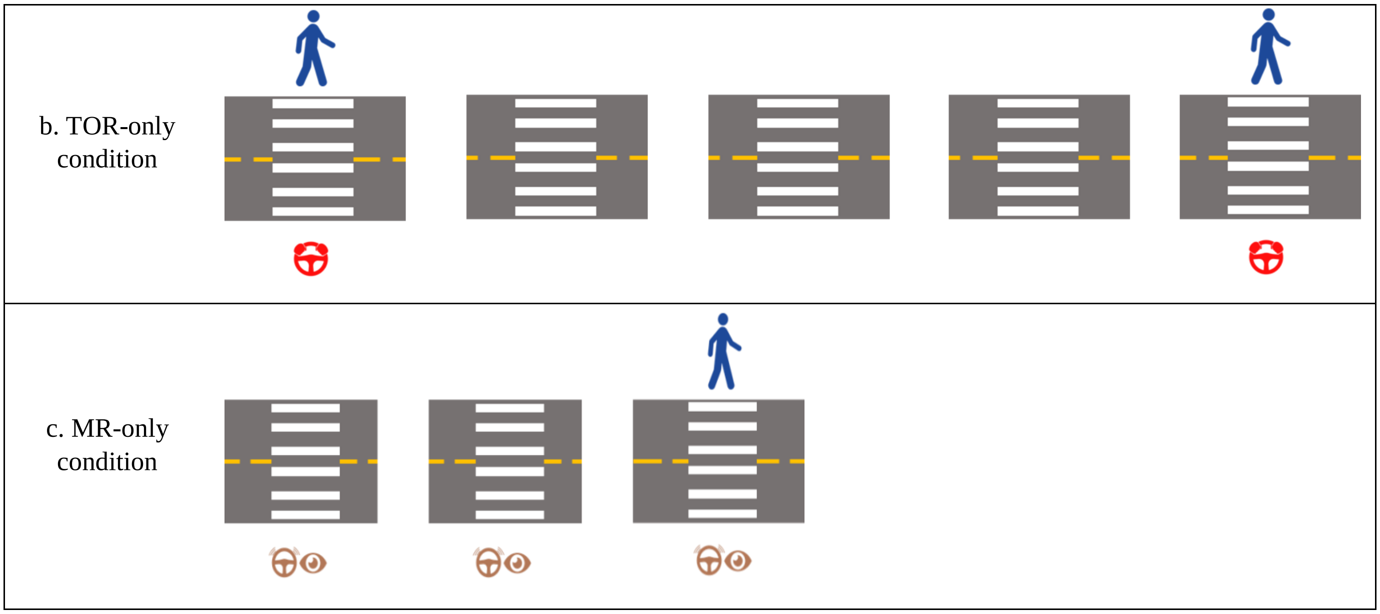


Figure 5. Illustration of the order the sessions and events for one participant. The MR+TOR and TOR-only conditions were counterbalanced, and the MR-only condition was always driven after the first two conditions. The sequences of the five scenarios in MR+TOR and TOR-only conditions were randomized for each participant. The sequence of the three scenarios in the MR-only condition was fixed as shown in c).

2.5. Non-driving tasks

The participants were instructed to play Angry Birds or Candy Crush (visual-motor tasks without sound) during automated driving on a handheld tablet PC (iPad 2) provided by the instructor. These games are self-paced and interruptible (Naujoks, Befelein, Wiedemann, & Neukum, 2017), meaning that participants could pause the game whenever they felt necessary to look up to the road.

2.6. Procedures

Upon arrival at the institute, the participants were welcomed and asked to read a consent form. The first part of the form contained an introduction to the experiment and the two automation systems. The form mentioned that participants would experience two systems: one with and one without the MR in the first two sessions, and that they would again experience the system with the MR in the third session. Moreover, they were informed that, in all three sessions, the TOR would be available if the critical events are detected successfully. The participants were instructed to keep their hands off the steering wheel and feet off the pedals during highly automated driving. Furthermore, they were asked to play the game during the experiment, and stop playing when the automation requests them to take control. They were also informed to stop playing the game and monitor the surroundings whenever they feel insecure, even when the automation provides no request. Participants were not informed about the specific type of event that would occur (pedestrians crossing the road), nor about the fact that the system would fail to provide a TOR.

After signing the consent form, the participants completed a questionnaire regarding their age, gender, and driving experience. Next, a handout with pictures for each of the automation-status icons was provided, and the non-driving tasks were introduced on the tablet. The participants were then led to the driving simulator. The positions of the seat, mirrors, and the steering wheel were adjusted to each participant's preference, and the eye-tracking system was calibrated.

At the beginning of the experiment, each participant drove a training session of approximately 4 minutes, during which they received verbal explanations from the experimenter. The participants started this training on a rural road and drove manually for around 2 minutes. Upon approaching an urban area, the participants received a notification from the system and pressed the button to activate the automation. In the urban area, the participant experienced an MR when approaching a zebra crossing without a critical event. Shortly afterwards, the participants received another MR and subsequently a TOR because of road construction ahead. The participant had to take over control by braking or steering to avoid a collision with the traffic cones in the ego lane. The training session ended after the participant drove past the construction area.

Next, the participants drove the three experimental sessions described in section 2.4. Before the session, they were informed which of the two systems (TOR-only or MR+TOR) they were about to experience. After each session, the participants took a break and completed a questionnaire about their workload (NASA-TLX) when performing the experiment, and rated the automated driving system they just experienced. The entire experiment lasted approximately 90 min per participant.

2.7. Dependent variables

The drivers’ behaviour during this study was assessed using the data recorded by the eye tracker, simulator software and self-report questionnaires.

2.7.1. Eye movements

Two gaze-based measures were used in this study.

- Eyes-on-road response time: defined as the time interval from the MR onset until the first detected glance on the road. In the TOR-only condition, the eyes-on-road response time is the interval from the TOR onset until the first detected glance on the road.
- The percentage time eyes-on-road: the percentage of time that glances were within the area of the windshield when the automation was active (i.e., periods when the vehicle was within 166.67 m before the zebra crossings were excluded). This measure describes whether participants showed different monitoring behaviour (i.e., voluntarily looking at the road) when using the two automation systems.

Glances shorter than 0.125 s were eliminated from the raw tracking data, in approximate agreement with the minimum possible fixation duration (ISO, 2014).

2.7.2. Take-over performance measures

The following measures were used to evaluate how quickly the participants responded to the MR and TOR.

- Hands-on-wheel time: the time interval measured from the moment a pedestrian became visible (i.e., the TOR onset if available) until the participant put at least one hand on the steering wheel, as measured with detection sensors in the steering wheel.
- Brake initiation time: the time interval measured from the moment a pedestrian became visible (i.e., the TOR onset if available) until the first detectable braking movement (first non-zero brake signal).
- Steer initiation time: The time interval measured from the moment a pedestrian became visible (i.e., the TOR onset if available) until the first detectable steering movement before the zebra crossing (exceeding 0.02 radians).
- Minimum TTC: The minimum time to collision (TTC) in scenarios where pedestrians were crossing the road. This measure was calculated after the first moment the driver pressed the brake. The minimum TTC was zero if a collision occurred.

- Maximum longitudinal deceleration: The maximum deceleration in scenarios where pedestrians crossed the road. This measure was calculated for moments the driver pressed the brake.

2.7.3. Subjective measures

After each session, participants completed questionnaires concerning workload, acceptance, usability, and trust. All the scores were linearly scaled to percentages.

- Mental workload: the workload was measured using the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988), which consists of six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. Each of the six items had 20 markers, and ranged from “low” to “high”. In the analysis, the score for the performance item was reversed from “low” to “high” to “high” to “low”.
- Acceptance: the acceptance scale developed by Van der Laan, Heino, and De Waard (1997) consists of nine questions with items scored -2 to +2 on a 5-point semantic differential scale. Scores were calculated for two dimensions: Usefulness (1. useful–useless, 3. bad–good, 5. effective–superfluous, 7.assisting–worthless, and 9. raising alertness–sleep-inducing) and Satisfaction (2. pleasant–unpleasant, 4. nice–annoying, 6. irritating–likeable, 8. undesirable–desirable). In the calculation of the usefulness and satisfaction scores, the scores for items 1, 2, 4, 5, 7 and 9 were reversed.
- Usability: Usability of the human-machine interface was assessed based on Nielsen’s Attributes of Usability (Nielsen, 1994). The participants expressed their degree of agreement with five statements regarding learnability (learning to operate the system was easy for me), efficiency (my interaction with the system was clear and understandable), memorability (it was easy to remember how to use the system), accuracy (it was easy to use the system quickly without making errors) and subjective satisfaction (the system was easy and comfortable to use) on a seven-tick Likert scale from disagree to agree.
- Trust: Trust in automation system was assessed using five items selected from a questionnaire by Jian, Bisantz, & Drury (2000). The participants expressed their degree of agreement on a seven-tick Likert scale regarding mistrust (the system behaves in an underhanded manner), harm (the system’s actions will have a harmful or injurious outcome), suspicion (I am suspicious of the system’s intent action, or outputs), confidence (I am confident in the system) and security (The system provides security). Differences between

the MR+TOR and TOR-only conditions were compared using paired t-tests, with a significance level of 0.05.

3. Results

3.1. Missing values and excluded data

Of the 41 participants, two participants experienced severe simulator sickness, and one participant had difficulties understanding the operation of the automation system. These three participants were excluded from all analyses. Furthermore, one participant’s eye-tracking data was lost due to an experimenter’s error, and the gaze calibration for three participants was not performed properly. Their eye tracking data were excluded from the eye-tracking analysis. Summarising, the data analysis is based on the driving performance data and the self-report data from 38 participants, and the eye tracking data from 34 participants.

One event from one participant in the TOR-only condition was excluded from all analyses, because the automation was deactivated before the event. Furthermore, in the TOR-only condition, one collision with a pedestrian occurred. This collision occurred because the driver intentionally did not brake to determine whether the car could brake automatically, as was discovered during the interview after the experiment. Only the eye tracking data from this event were included in the analysis. In addition, the eyes-on-road response time of one event in the MR+TOR condition was excluded due to missing data. Table 1 provides an overview of the number of events and responses for the main part of the experiment, that is, the MR+TOR and the TOR-only conditions. It can be seen that the MR system generally worked as intended, as participants had their eyes on the road at the moment of the TOR in 61 out of 68 cases. In the remaining 7 cases, participants monitored the road but had their attention allocated back to the secondary task when the TOR was provided. Furthermore, in situations without pedestrians, braking occurred in only 1 out of 114 trials, and in situations with pedestrians, participants braked in all cases.

Table 1. Number of events and responses in the MR+TOR and TOR-only conditions.

Condition	**Pedestrian-crossing scenarios**	**Total**		**Braking action**	**Full stop**	**Crash**	**Eyes on the road at the moment of the MR**	**Eyes on the road at the moment of the TOR**
		Driving data included	**Eye gaze data included**					

MR+TOR	**MR (i.e., no pedestrians)**	114	102	1	0	—	14	—
	MR+TOR (i.e., with pedestrians)	76	68	76	50	0	9	61
TOR-only	**TOR (with pedestrians)**	74	67	74	50	1	—	15

3.2. Gaze behaviour

We analysed the allocation of the participants' eyes on the road and instrument cluster while they were approaching the zebra crossings. Response times were calculated starting with the onset of the TOR and MR. The visualizations were performed using the position of the participant's car on the *x*-axis, since the TOR/MR was triggered based on the position of the car, which is consistent with how sensors work in real systems. Furthermore, by using distance instead of time on the *x*-axis, spatial relationships can be assessed intuitively; this would be impossible when using time on the *x*-axis, as different participants take different amounts of time to complete the scenario, depending on how they brake and use the throttle to accelerate again.

Figure 6 shows how the participants shifted their attention back to the road after receiving an MR or TOR as a function of travelled distance, for three scenarios: MR without pedestrians crossing the road, MR followed by a TOR (i.e., pedestrians crossing the road), and TOR in TOR-only conditions (i.e., without an MR).

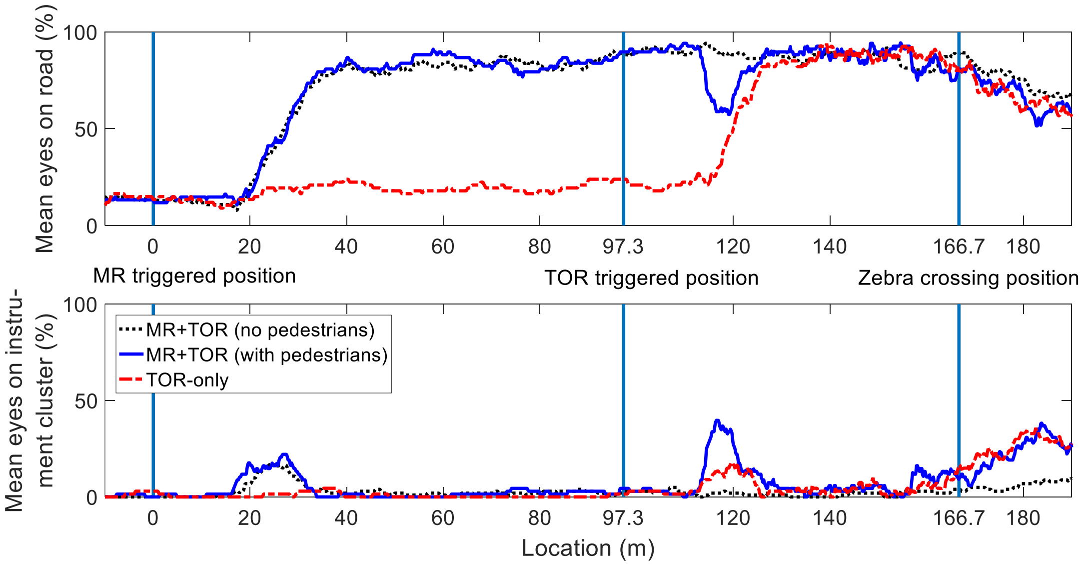


Figure 6. Participants' visual attention allocation on the windshield (upper plot) and instrument cluster (lower plot) for the MR+TOR and TOR-only conditions. Three vertical lines from left to right are the locations of the MR (0 m; time to zebra crossing = 12 s), TOR (97.3 m; time to zebra crossing = 5 s), and zebra crossing (166.7 m).

From Figure 6, it can be seen that participants, on the aggregate, showed an eye-movement response towards the road and instrument cluster between 20 m to 40 m after the onset of an MR (in the MR+TOR condition) or a TOR (in the TOR-only condition). After passing the zebra crossing, some participants shifted their attention from the road to the instrument cluster. This attention shift to the instrument cluster may be because participants attempted to assess their speed or the automation status when accelerating again, after having braked for the pedestrians (see Figure 7 for a figure with the mean speed).

The mean eyes-on-road response time to MRs in the MR+TOR condition was 1.85 s (SD = 0.51 s), whereas the eyes-on-road response time to the TOR in the TOR-only condition was 1.76 s (SD = 0.73 s) (after removing 23 from 170 events in the MR+TOR condition and 15 from 67 events in the TOR-only condition in which participants already had their eyes on road). According to a paired t-test, this difference in eyes-on-road-time was not statistically significant (see Table 2 and Figure 8). The maximum eyes-on-road time in the MR+TOR condition was 3.84 s, which means that all participants responded to the MR before the TOR, which was presented 7 s after the MR.

Concerning the eye-gaze behaviour during automated driving in between the zebra crossings, the average percentage of time with eyes on road across the participants for the MR+TOR and TOR-only conditions were 17.71% and 16.43% (SD = 13.98%, 14.05%), respectively, a difference that was not statistically significant between the two conditions (see Table 2 and Figure 9a). This finding indicates that participants were equivalently distracted in both conditions, as could be expected.

3.3. Take-over performance

Figure 7 shows drivers' braking actions in the situations where pedestrians were crossing the road and TORs were provided. It can be seen that, on average, participants applied slightly earlier braking, and reduced their speed earlier in the MR+TOR condition than in the TOR condition. Table 2 shows the corresponding descriptive statistics for the five take-over measures in the MR+TOR and TOR-only conditions, as well as pairwise comparisons between these conditions. The hands-on-wheel was 3.02 s faster and braking was 0.44 s faster in the MR+TOR condition than in the TOR-only condition. Thus, the results in Figure 7 and Table 2 indicate that the MRs effectively raised drivers' readiness to make the transition back to manual control of their vehicle. In the MR+TOR condition, the participants even put their hands on the steering wheel on average *before* the onset of the TOR. In Figure 8, the sequence of participants' responses is illustrated for eyes-on-road, hands-on-wheel, braking, and steering. The observed minimum TTC in the MR+TOR condition was 0.27 s longer than in TOR-only condition (consistent with the fact that participants braked earlier), indicating a safer response. However, the maximum deceleration was not significantly different between these two conditions (see Table 2, Figure 9b and Figure 9c).

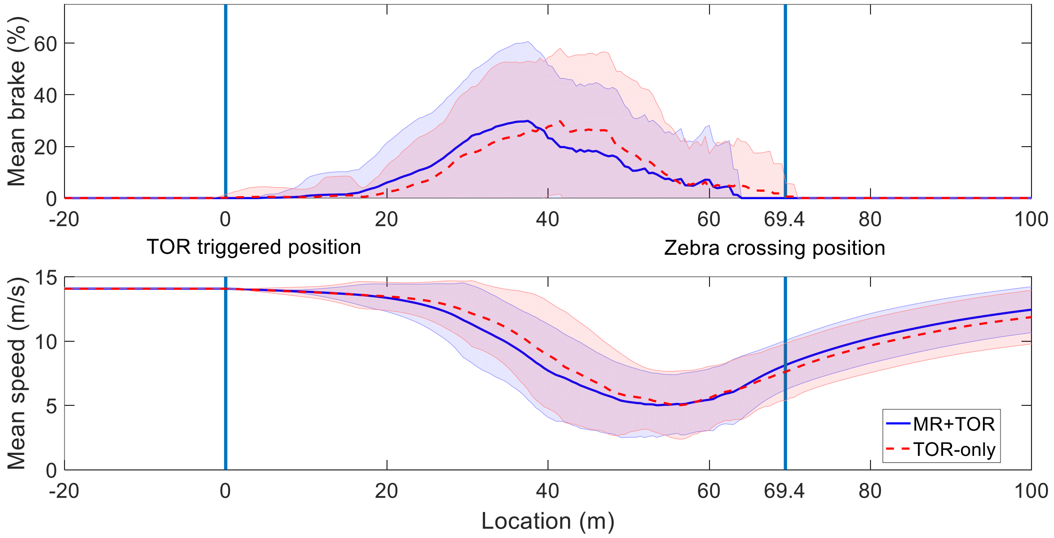


Figure 7. Means and standard deviations across events of the brake position and driving speed in the take-over scenarios in the MR+TOR and TOR-only conditions as a function of travelled distance. The vertical lines mark the start of the TOR (0 m) and the position of the zebra crossing (69.4 m). Note that these are averages, which means that these graphs cannot be used to make inferences about the behaviour of individual participants. For example, the minimum averaged speed in this graph is about 5 m/s, while the majority of the participants came to a full stop.

Table 2. Means and standard deviations of participants for gaze behaviour and take-over response times measures in the MR+TOR and TOR-only conditions, and pairwise comparisons between the two conditions.

		Eyes-on-road response time (s)	**Eyes-on-road percentage (%)**	**Hands-on-wheel time (s)**	**Brake initiation time (s)**	**Steer initiation time (s)**	**Maximum deceleration (m/s^2)**	**Minimum TTC (s)**
MR+TOR	M (SD)	1.85 (0.51)	17.71 (13.98)	-0.38 (3.26)	1.86 (0.59)	7.91 (5.49)	-8.42 (0.97)	2.83 (0.54)
TOR-only	M (SD)	1.76 (0.73)	16.43 (14.05)	2.64 (1.88)	2.30 (0.61)	8.72 (4.32)	-8.72 (1.00)	2.56 (0.72)
Paired t-test	t	1.45	0.75	-5.94	-4.53	-0.54	1.46	3.24
	df	28	33	37	37	29	37	37
	p	0.159	0.462	**<0.001**	**<0.001**	0.594	0.152	**0.003**
	r	0.44	0.75	0.35	0.50	0.086	0.16	0.70

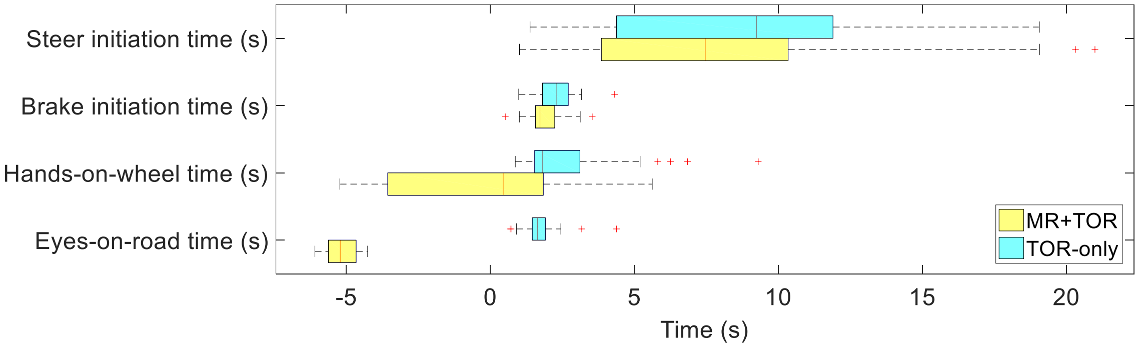


Figure 8. Box plots at the level of participants for eyes-on-road, hands-on-wheel, braking, and steering. The figure is created so that the temporal sequence of events is illustrated. The TOR is provided at 0 s, while the MR is provided at -7 s. The eyes-on-road time in the MR+TOR condition is the response to the MR; the other measures are all with respect to the TOR. Negative values indicate that the corresponding behaviour occurred before the TOR onset.

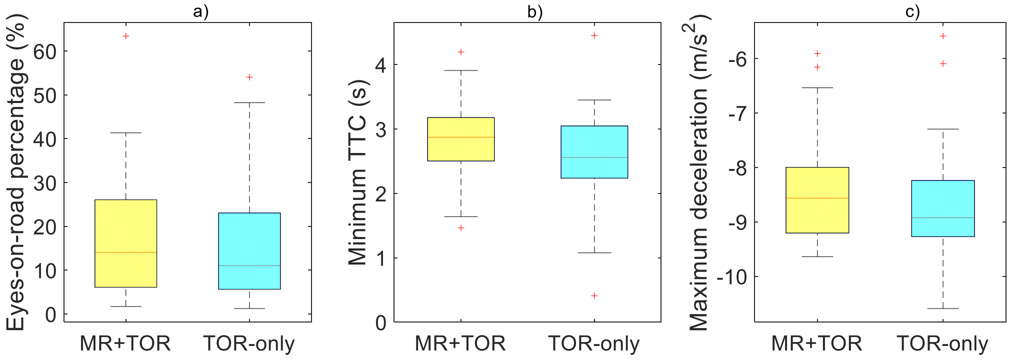


Figure 9. Boxplots at the level of participants for the a) percentage time eyes-on-road, b) minimum TTC, and c) maximum deceleration.

3.4. Subjective evaluation

3.4.1 NASA-TLX

The overall workload is the average score of the six questions in NASA-TLX. There was a statistically significant difference in the scores of the MR+TOR (M = 20.6, SD = 13.4) and TOR-only (M = 26.5, SD = 13.0) conditions, t(37)= -3.39, p = 0.002, r = 0.67. The temporal demand, frustration, and effort items yielded significantly lower scores in the MR+TOR as compared to the TOR-only condition (Table 3).

Table 3. Means and standard deviations of the self-reported workload per condition.

		Overall workload (%)	**Mental demand (%)**	**Physical demand (%)**	**Temporal demand (%)**	**Performance (%)**	**Frustration (%)**	**Effort (%)**
MR+TOR	M (SD)	20.6 (13.4)	21.5 (20.5)	15.0 (14.2)	25.3 (22.3)	14.4 (17.7)	13.7 (19.3)	13.6 (13.7)
TOR-only	M (SD)	26.5 (13.0)	26.0 (21.2)	16.9 (16.1)	36.7 (28.0)	17.0 (19.3)	21.6 (25.7)	22.6 (19.6)
Paired t-test	t(37)	-3.39	-1.73	-0.90	-2.82	-0.89	-2.14	-3.16
	p	**0.002**	0.092	0.375	**0.008**	0.378	**0.039**	**0.003**
	r	0.67	0.70	0.62	0.54	0.52	0.52	0.49

Note. The scores on the items are from low (0%) to high (100%), except for the performance item, which is expressed from high (0%) to low (100%).

3.4.2. Usefulness and Satisfaction Scales

The mean usefulness score for the MR+TOR condition (M = 85.0, SD = 10.6) was significantly higher than for TOR-only condition (M= 79.1, SD= 11.3), t(37) = 3.02, p = 0.005, r = 0.39. Similarly, participants were more satisfied with the system in the MR+TOR condition (M = 88.5, SD = 12.3) compared to the TOR-only condition (M = 80.6, SD = 17.1), t(37)= 3.42, p = 0.002, r = 0.57.

3.4.3. Usability

The usability score (average of the five usability items) was not significantly different between the MR+TOR condition (M = 97.0, SD = 5.4) and the TOR-only condition (M = 96.1, SD = 5.8), t(37) = 1.25, p = 0.220, r = 0.64.

3.4.4. Trust

All trust-related scores for the MR+TOR and TOR-only conditions are shown in Table 4. All items showed higher trust in the MR+TOR condition, especially for harm, confidence and security. Additionally, when asked about their preference between the two systems, 31 out of 38 participants preferred the MR+TOR to the TOR-only system.

Table 4. Means and standard deviations of participants for the responses to the trust questionnaire, and results of paired t-tests between conditions

		Mistrust	**Harm**	**Suspicion**	**Confidence**	**Security**
MR+TOR	M (SD)	30.6 (34.6)	18.4 (23.2)	20.2 (27.2)	84.2 (18.2)	84.2 (15.0)
TOR-only	M (SD)	35.5 (34.5)	28.5 (25.7)	25.9 (27.3)	75.0 (23.8)	73.7 (21.4)
Paired t-test	t	-0.82	-3.38	-1.68	3.39	4.26
	df	36	37	37	37	37
	p	0.419	**0.002**	0.102	**0.002**	**<0.001**
	r	0.54	0.72	0.70	0.71	0.71

3.5. Monitoring request without take-over request

The third condition ‘MR-only’, of which the results were not provided above, was included at the end of the experiment. Because this condition had a different design, the results are discussed separately in the present section. The MR-only condition was included to study whether participants relied on the TOR to follow the MR and to see if participants would still respond to a critical situation if no TOR was provided.

From the 38 participants, three crashed into the pedestrians in the last scenario. Participants’ eyes were on the road and hands on the wheel during all three crashes, but participants did not intervene (see also Victor et al., 2018). In a post-experiment interview, all three participants reported their expectation and reliance on the TOR. An overview of the eye movement and braking actions in the pedestrians crossing scenarios in MR+TOR and TOR-only conditions is provided in Figure 10. It shows that, on average, participants applied later and harder braking in the MR-only condition than in the MR+TOR condition. Moreover, it is clear that people in the MR-only condition focused on the road rather than on the instrument cluster, presumably because no TOR was shown on the instrument cluster.

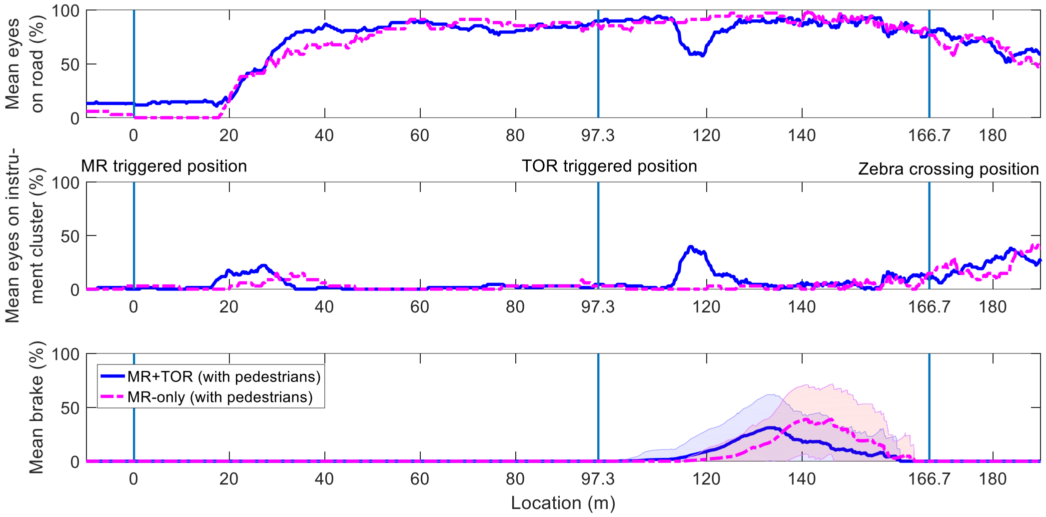


Figure 10. Participants' mean visual attention allocation across events on the windshield (upper plot) and instrument cluster (middle plot) and means and standard deviations across events of the brake position (lower plot) in the pedestrians crossing scenarios in the MR+TOR and MR-only conditions as a function of travelled distance. Three vertical lines from left to right are the locations of the MR (triggered position = 0 m), TOR (triggered position = 97.3 m), and zebra crossing (166.7 m).

We also compared three performance measures (maximum deceleration, brake initiation time, minimum TTC) in the pedestrian crossing scenarios between the MR+TOR and MR-only conditions (Table 5). The three collisions were not included in the comparison because the brakes were not applied. We assessed learning effects by comparing the two scenarios with pedestrians within the MR+TOR condition. Next, we tested whether the learning trend was counteracted by the lack of a TOR, by comparing the MR-only event ('no TOR') with the second MR+TOR event.

As shown in Table 5 and Table 6, participants braked significantly earlier and with less deceleration after the second TOR compared to the first TOR in the MR+TOR condition. However, this learning effect did not continue into the MR-only condition: In the MR-only condition, participants braked significantly later and harder compared to the second TOR of the MR+TOR condition. No statistically significant difference of minimum TTC was observed in the two pedestrian-crossing events of the MR+TOR condition. However, in the MR-only condition, the minimum TTC was significantly shorter compared to the first and second TOR of the MR+TOR condition. Summarizing, participants braked later in the MR-only condition (TOR only) as compared to MR+TOR condition, *despite* an expected learning effect in the opposite direction.

Table 5. Means and standard deviations of participants for the braking measures in the MR+TOR and MR-only conditions

	Maximum deceleration (m/s^2)	**Brake initiation time (s)**	**Minimum TTC (s)**
First TOR (MR+TOR condition)	-8.84 (0.93)	2.06 (0.71)	2.75 (0.66)
Second TOR (MR+TOR condition)	-8.00 (1.45)	1.82 (0.63)	2.91 (0.60)
No TOR (MR-only condition)	-9.10 (0.64)	2.37 (0.55)	1.98 (0.82)

Table 6. Results of paired t-tests between performance measures regarding the first TOR in the MR+TOR condition, the second TOR in the MR+TOR condition, and no TOR in the MR-only condition.

	Maximum deceleration (m/s^2)				**Brake initiation time (m)**				**Minimum TTC (s)**			
	Second TOR (MR+TOR condition)		**No TOR (MR-only condition)**		**Second TOR (MR+TOR condition)**		**No TOR (MR-only condition)**		**Second TOR (MR+TOR condition)**		**No TOR (MR-only condition)**	
	t(37)	p	t(34)	p	t(37)	p	t(34)	p	t(37)	p	t(34)	p
First TOR (MR+TOR condition)	-3.52	**0.001**	1.33	0.192	2.36	**0.023**	-2.96	**0.006**	-1.44	0.159	6.28	**<0.001**
Second TOR (MR+TOR condition)			4.94	**<0.001**			-6.91	**<0.001**			8.33	**<0.001**

4. Discussion

4.1. Main findings

The main aim of this study was to investigate whether drivers are responsive to MRs by redirecting their attention to the road, whether drivers unnecessarily take over control when no action is needed, and whether drivers have a shorter take-over time when being forewarned by the MR as compared to when receiving only a TOR. Accordingly, a systematic comparison of participants' behaviours was made between an MR+TOR system and a traditional TOR-only system.

The results indicate that participants showed strong compliance with the MRs: Participants were responsive to the MR by looking at the road, and several participants placed their hands on the steering wheel without specifically being asked to do so. These behaviours indicate that drivers were preparing themselves for a possible take-over. With their eyes on the road and their hands already on the wheel, the drivers responded faster to TORs in the MR+TOR condition in comparison to the TOR-only condition. The longer minimum TTC values measured in the MR+TOR condition as compared to the TOR-only condition indicate that the MRs helped improve safety. Although the observed improvements (e.g., 0.44 seconds faster brake response time) may seem modest on an absolute scale, we argue that they can translate into large safety benefits. For example, if decelerating with 8 m/s^2, 0.44 s longer braking implies an additional speed reduction of 13 km/h. This speed difference can be expected to yield substantial improvements in the probability of surviving a crash (Joksch, 1993).

Additionally, we found only one unneeded braking action when no pedestrians were crossing the road, which means the MRs hardly caused unnecessary take-overs when no action was needed. We also found that drivers experienced lower subjective workload, higher acceptance (usefulness and satisfaction), and higher trust for the MR+TOR condition as compared to the TOR-only condition, whereas there were no statistically significant differences in experienced usability. In other words, MRs not only yielded positive effects on behaviour, but were generally also experienced as positive. Finally, the presentation of MRs did not change drivers' attention allocation during the automated driving periods, indicating that drivers still felt comfortable to perform the non-driving task in between MRs.

Summarising, the MR concept worked as intended: It permitted drivers to be engaged in a non-driving task (as in a highly automated driving system), and still ensured that participants were attentive and prepared for an upcoming event (as in a partially automated driving system). Thus, our findings show that MRs promote a gradual transition between being disengaged from the driving task and actually taking over control. Put differently, the MRs effectively exploit the idea that automated driving can independently involve driver monitoring transitions and control transitions (Lu et al., 2016). Our results align with previous studies (Gold et al., 2013; Cohen-Lazry et al., 2017; Dziennus et al., 2016; Yang et al., 2017; Helldin et al., 2013), which have shown that MRs and other types of uncertainty indicators stimulate driver to allocate attention to the road when encountering an unpredictable driving environment, in turn yielding improved responses in critical situations.

4.2. Reliance on the TOR

An additional aim of this study was to examine whether people over-rely on the TOR, despite the fact that they have received an MR prompting them to monitor the driving environment. Previous research suggests that notifications with a low probability of requiring an actual intervention may cause under-reliance (Tijerina et al., 2017), a phenomenon also known as the cry-wolf effect (Bliss, 1993; Breznitz, 1983; Dixon, Wickens, & McCarley, 2007; Wickens, Dixon, Goh, & Hammer, 2005; Zabyshny & Ragland, 2003). The opposite effect was observed in the final trial of our experiment: When drivers who were previously exposed to perfectly reliable TORs were provided with only an MR, they showed worse take-over performance as compared to the MR+TOR condition. Three out of 38 participants collided with the pedestrians, whereas the other participants showed higher mean response times, more severe braking, and a smaller minimum TTC as compared to the MR+TOR condition, despite the fact that they were looking at the driving environment and were told that the TOR would be available only if the critical event were detected successfully. This overreliance may have been caused by the fact that participants were conditioned to respond to the TORs, not to the hazards (i.e., pedestrians) themselves. It is also possible that participants had built inappropriately high trust in the TORs, because all preceding pedestrian crossing events came with a TOR. Lee and See (2004) argued that human trust needs to be calibrated according to the context and characteristics of automation. Further research could investigate how to prevent overreliance on TORs. One idea is to examine whether a variable ratio of the number of TORs over the number of MRs could affect driver trust levels and their responses to the MR.

4.3. Limitations

This study has several limitations. First, we presented pedestrian crossing scenarios only, which may have contributed to reduced response times due to familiarity. In future research, a larger variety of scenarios could be tested, including time-critical situations and voluntary transitions such as merging or exiting the highway. Future research might also use a between-subjects rather than within-subject design to prevent carry-over effects. However, it is cautioned that between-subjects designs require a substantially larger sample size in order to maintain adequate statistical power. Second, this study used fixed time budgets for monitoring (i.e., 12 seconds before the collision) and taking over (i.e., 5 seconds before the collision), which may have led to specific expectations about the timing of taking back control. The time budget between an MR and a TOR could be further investigated. If an MR is provided early, drivers may lose attention again, whereas if an MR is provided late, there may be insufficient time to prepare for taking over. Third, the MRs were tested in a rather short experiment. It is possible that non-compliance to the MRs becomes apparent if drivers were to use the system for a longer time on real roads. Finally, simulator fidelity may be an issue. The absence of physical motion cues may have an effect on how drivers brake (Boer et al., 2000; Siegler et al., 2001) and may have reduced drivers' awareness of the automation mode (Cramer, Siedersberger & Bengler, 2017). It is also possible that the presentation of virtual hazards, rather than real hazards, has reinforced the "wait and see" behaviour in the MR-only condition.

5. Conclusion

In summary, the observed effects of MRs are promising: the MRs directed the drivers' attention to the road without the necessity for them to take over control of the vehicle, improve the response to a subsequent TOR. Furthermore, the MR+TOR was positively evaluated for workload, usefulness and satisfaction. We argue that automated driving systems that provide only TORs are not exploiting the richness of sensory information, both of the human and the automation sensor suite. The concept of MR makes use of the fact that automated driving systems have variable certainty about the situation. In our case, we demonstrated the MR concept when the car approaches a zebra crossing, a part of the road entailing a high likelihood that the driver has to take over control.

The simulated MR is realistic in terms of automated driving technology. Differential GPS, HD maps, and traffic data could be used as inputs to the automated driving system to provide an MR when approaching a potentially critical road section, unlike camera and lidar, which are constrained by their detection ranges. Finally, we caution that the provision of MRs does not guarantee that no collisions will occur. We showed that when the automated driving system fails to detect a hazard and accordingly fails to provide a TOR, a proportion of drivers still crashed even though their eyes were on the road. Future research should be conducted on the topic of overreliance on take-over requests and individual differences in the use of automated vehicles.

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References

Balaud, M. (2015). *Likelihood alarm systems: the impact of the base rate of critical events, the cost of alarm validity information, and the number of stages on operator's performance* (Doctoral dissertation). Technische Universität Berlin, Germany.

Beller, J., Heesen, M., & Vollrath, M. (2013). Improving the driver–automation interaction: An approach using automation uncertainty. *Human Factors, 55*, 1130-1141. doi:10.1177/0018720813482327

Bliss, J. P. (1993). *The cry-wolf phenomenon and its effect on operator responses* (Unpublished doctoral dissertation). University of Central Florida, Orlando.

Boer, E. R., Yamamura, T., Kuge, N., & Girshick, A. (2000). Experiencing the same road twice: A driver centered comparison between simulation and reality. *Proceedings of Driving Simulation Conference* (pp. 33–55). Paris, France.

Brandenburg, S., & Epple, S. (2018). Designing the transition from highly automated driving to manual driving: a study of drivers' preferences. *Proceedings of the 6th Humanist Conference.* The Hague, Netherlands.

Breznitz, S. (1983). *Cry wolf: The psychology of false alarms.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Carsten, O., & Martens, M. H. (2018). How can humans understand their automated cars? HMI principles, problems and solutions. *Cognition, Technology & Work*. 1-18. doi:10.1007/s10111-018-0484-0

Cohen-Lazry, G., Borowsky, A., & Oron-Gilad, T. (2017). The effects of continuous driving-related feedback on drivers' response to automation failures. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 61, pp. 1980–1984). doi:10.1177/1541931213601974

Cramer, S., Siedersberger, K. H., & Bengler, K. (2017). Active vehicle pitch motions as feedback-channel for the driver during partially automated driving. *Workshop Fahrerassistenz und Automatisiertes Fahren, Uni-DAS e. V (Ed.)* (pp. 74-83). Walting, Germany.

Dixon, S. R., Wickens, C. D., & McCarley, J. S. (2007). On the independence of compliance and reliance: Are automation false alarms worse than misses? *Human Factors*, *49*, 564–572. doi:10.1518/001872007X215656

Dziennus, M., Kelsch, J., & Schieben, A. (2016). Ambient light based interaction concept for an integrative driver assistance system - a driving simulator study. *Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2015 Annual Conference.*, 171–182.

Eriksson, A., & Stanton, N. A. (2017). Takeover time in highly automated vehicles: noncritical transitions to and from manual control. *Human Factors*, *59*, 689–705. doi:10.1177/0018720816685832

Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice*, *77*, 167–181. doi:10.1016/j.tra.2015.04.003

Gold, C., Damböck, D., Lorenz, L., & Bengler, K. (2013). “Take over!” How long does it take to get the driver back into the loop? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 57, pp. 1938–1942). doi:10.1177/1541931213571433

Gold, C., Lorenz, L., Damböck, D., & Bengler, K. (2013). Partially automated driving as a fallback level of high automation. *6. Tagung Fahrerassistenzsysteme*. Munich, Germany.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. *Advances in Psychology*, *52*, 139–183. doi:10.1016/S0166-4115(08)62386-9

Helldin, T., Falkman, G., Riveiro, M., & Davidsson, S. (2013). Presenting system uncertainty in automotive UIs for supporting trust calibration in autonomous driving. *Proceedings of the 5th International Conference on Proceedings* *of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 210–217). doi:10.1145/2516540.2516554

ISO 15007-1:2014. (2014). Road vehicles – Measurement of driver visual behaviour with respect to transport information and control systems – Part 1: Definitions and parameters. Geneva, Switzerland: International Organization for Standardization (ISO)

Jian, J. Y., Bisantz, A. M., & Drury, C. G. (2000). Foundations for an empirically determined scale of trust in automated systems. *International Journal of Cognitive Ergonomics, 4*, 53–71. doi:10.1207/S15327566IJCE0401_04

Joksch, H. C. (1993). Velocity change and fatality risk in a crash—A rule of thumb. *Accident Analysis and Prevention*, *25*, 103–104. doi:10.1016/0001-4575(93)90102-3

Kühn, M., & Hannawald, L. (2014). Driver assistance and road safety. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.) *Handbook of Driver Assistance Systems: Basic Information, Components and Systems for Active Safety and Comfort* (pp. 1–17). Springer International Publishing.

Kyriakidis, M., Happee, R., & De Winter, J. C. F. (2015). Public opinion on automated driving: results of an international questionnaire among 5000 respondents. *Transportation Research Part F: Traffic Psychology and Behaviour, 32*, 127–140. doi:10.1016/j.trf.2015.04.014

Lapoehn, S., Dziennus, M., Utesch, F., Kelsch J., Schieben, A., Dotzauer M., Hesse, T., Köster, F. (2016). Interaction design for nomadic devices in highly automated vehicles. *Mensch und Computer 2016–Workshopband.* Aachen, Germany.

Large, D. R., Burnett, G. E., Morris, A., Muthumani, A., & Matthias, R. (2017). Design implications of drivers' engagement with secondary activities during highly-automated driving - a longitudinal simulator study. *Road Safety and Simulation International Conference (RSS2017).* The Hague, The Netherlands.

Lee, J. D., & See, K. A. (2004). Trust in automation: designing for appropriate reliance. *Human Factors*, *46*, 50–80. doi:10.1518/hfes.46.1.50_30392

Louw, T., Markkula, G., Boer, E., Madigan, R., Carsten, O., & Merat, N. (2017a). Coming back into the loop: Drivers' perceptual-motor performance in critical events after automated driving. *Accident Analysis & Prevention, 108,* 9–18. doi:10.1016/j.aap.2017.08.011

Louw, T., Madigan, R., Carsten, O., & Merat, N. (2017b). Were they in the loop during automated driving? Links between visual attention and crash potential. *Injury Prevention, 23,* 281-286. doi:10.1136/injuryprev-2016-042155

Lu, Z., Coster, X., & De Winter, J. C. F. (2017). How much time do drivers need to obtain situation awareness? A laboratory-based study of automated driving. *Applied Ergonomics*, *60,* 293–304. doi:10.1016/j.apergo.2016.12.003

Lu, Z., Happee, R., Cabrall, C. D. D., Kyriakidis, M., & De Winter, J. C. F. (2016). Human factors of transitions in automated driving: a general framework and literature survey. *Transportation Research Part F:Traffic Psychology and Behaviour, 43,* 183–198. doi:10.1016/j.trf.2016.10.007

Meyer, G., & Deix, S. (2014). Research and innovation for automated driving in Germany and Europe. In G. Meyer & S. Beiker (Eds.), *Road Vehicle Automation* (pp. 71–81), Springer. doi:10.1007/978-3-319-05990-7_7

Mok, B., Johns, M., Miller, D., & Ju, W. (2017). Tunneled in: Drivers with active secondary tasks need more time to transition from automation. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (pp. 2840-2844). doi:10.1145/3025453.3025713

Naujoks, F., Befelein, D., Wiedemann, K., & Neukum, A. (2017). A review of non-driving-related tasks used in studies on automated driving. In N. A. Stanton (Ed.), *Advances in Intelligent Systems and Computing*, *Advances in Human Aspects of Transportation.* Springer. doi:10.1007/978-3-319-60441-1_52

Naujoks, F., Kiesel, A., & Neukum, A. (2016). Cooperative warning systems: The impact of false and unnecessary alarms on drivers' compliance. *Accident Analysis & Prevention, 97,* 162-175. doi:10.1016/j.aap.2016.09.009

Naujoks, F., Purucker, C., Neukum, A., Wolter, S., & Steiger, R. (2015). Controllability of partially automated driving functions–does it matter whether drivers are allowed to take their hands off the steering wheel? *Transportation Research Part F: Traffic Psychology and Behaviour, 35*, 185–198. doi:10.1016/j.trf.2015.10.022

Nielsen, J. (1994). *Usability Engineering.* San Diego, California: Academic Press.

SAE International. (2016). Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicle (J3016_201609).

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2008). Situation awareness, mental workload, and trust in automation: Viable, empirically supported cognitive engineering constructs. *Journal of Cognitive Engineering and Decision Making, 2,* 140–160.

Samuel, S., Borowsky, A., Zilberstein, S., & Fisher, D. L. (2016). Minimum time to situation awareness in scenarios involving transfer of control from an automated driving suite. *Transportation Research Record: Journal of the Transportation Research Board, 2602,* 115–120. doi:10.3141/2602-14

Siegler, I., Reymond, G., Kemeny, A., & Berthoz, A. (2001). Sensorimotor integration in a driving simulator: Contributions of motion cueing in elementary driving tasks. *Proceedings of the Driving Simulation Conference* (pp. 21–32). Sophia-Antipolis, France.

Skitka, L. J., Mosier, K. L., & Burdick, M. (1999). Does automation bias decision-making? *International Journal of Human-Computer Studies, 51,* 991–1006. doi:10.1006/ijhc.1999.0252

Tijerina, L., Blommer, M., Curry, R., Swaminathan, R., Kochhar, D. S., & Talamonti, W. (2017). An exploratory study of driver response to reduced system confidence notifications in automated driving. *IEEE Transactions on Intelligent Vehicles, 1,* 325–334. doi:10.1109/TIV.2017.2691158

Van den Beukel, A. P., Van der Voort, M. C., & Eger, A. O. (2016). Supporting the changing driver's task: Exploration of interface designs for supervision and intervention in automated driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 43,* 279–301. doi:10.1016/j.trf.2016.09.009

Van der Laan, J. D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies, 5,* 1–10. doi:10.1016/S0968-090X(96)00025-3

Victor, T. W., Tivesten, E., Gustavsson, P., Johansson, J., Sangberg, F., Ljung Aust, M. (2018). Automation expectation mismatch: Incorrect prediction despite eyes on threat and hands on wheel. *Human Factors, 60*, 1095–1116. doi:10.1177/0018720818788164

Watzenig, D., & Horn, M. (2017). Introduction to automated driving. In Watzenig D. & Horn M. (Eds.), *Automated Driving* (pp. 3–16), Springer. doi:10.1007/978-3-319-31895-0_1

Wickens, C., Dixon, S., Goh, J., & Hammer, B. (2005). Pilot dependence on imperfect diagnostic automation in simulated UAV flights: an attentional visual scanning analysis (Tech Rep. AHFD-05 02/MAAD-05-02). University of Illinois, Urbana-Champaign, IL.

Wiczorek, R., Balaud, M., & Manzey, D. (2015). Investigating benefits of likelihood alarm systems in presence of alarm validity information. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 59, pp. 850–854). doi:10.1177/1541931215591255

Willemsen, D., Stuiver, A., & Hogema, J. (2015). Automated driving functions giving control back to the driver: a simulator study on driver state dependent strategies. *24th International Technical Conference on Enhanced Safety of Vehicles (ESV)* (No. 15-0109).

Yang, Y., Götze, M., Laqua, A., Dominioni, G. C., Kawabe, K., & Bengler, K. (2017). A method to improve driver's situation awareness in automated driving. *Proceedings of the Human Factors and Ergonomics Society Europe Chapter*, 29–47.

Zabyshny, A. A., & Ragland, D. R. (2003). False alarms and human-machine warning systems. *UC Berkeley: Safe Transportation Research & Education Center.* Retrieved from https://safetrec.berkeley.edu/sites/default/files/publications/escholarship_uc_item_88w8b8g3.pdf

Zeeb, K., Härtel, M., Buchner, A., & Schrauf, M. (2017). Why is steering not the same as braking? The impact of non-driving related tasks on lateral and longitudinal driver interventions during conditionally automated driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 50*, 65–79. doi:10.1016/j.trf.2017.07.008

Zhang, B., De Winter, J. C. F., Varotto, S., Happee, R., & Martens, M. H. (2018). *Determinants of take-over time from automated driving: a meta-analysis of 129 studies*. Manuscript submitted for publication.

Zhang, B., Wilschut, E. S., Willemsen, D. M. C., & Martens, M. H. (2017). Driver response times when resuming manual control from highly automated driving in truck platooning scenarios. *Road Safety and Simulation International Conference.* The Hague, The Netherlands. doi:10.13140/RG.2.2.28249.01127