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An empirical exploration of the impact of transition of control on situation awareness for potential hazards

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An experiment about the hazard perception capabilities of drivers after interruption in a video-based scanning task

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Summary

The Directorate-General of Highways, Waterways, and Water Systems (Rijkswaterstaat in Dutch) of the Ministry of Infrastructure and the Environment (Ministerie van Infrastructuur en Milieu (IenM in Dutch) has commissioned SWOV to conduct an experiment about transition of control in highly and fully automated vehicles from the perspective of the driver. Transition of control is the switch from (fully) automated driving to manual driving while in traffic. When drivers are driven in a (fully) automated vehicle and the system fails in the execution of the driving task, makes a mistake, or when drivers choose to drive the vehicle manually, drivers have to switch from automatic to manual mode. The study was intended to demonstrate the impact in highly controlled laboratory settings. The rationale for conducting a laboratory experiment was to control for as many confounding factors as possible without exposing participants to dangers in real traffic. As such, the results are an indication of the possible effects of transition of control on situation awareness in real traffic. However, the laboratory settings were too remote from real-life situations so that nothing can be concluded about the degree of impairment of situation awareness and its duration in real traffic on the basis of the results of this study.

This study has investigated whether the detection of latent hazards diminished *after* completion of a short, secondary task and, if so, how long this diminished situation awareness lasted. Three groups of experienced drivers watched thirteen animated video clips filmed from a driver perspective while their gaze directions were recorded. Each video clip lasted approximately 40 s. A high-priority latent hazard was present in each video clip. Latent hazards are traffic situations with a high likelihood to develop into a situation in which a crash is likely to occur should the latent hazard materialize. In none of the video clips did the latent hazard actually materialize. For half of the participants in a group, 50% of the videos were interrupted for 5 s by a screen with words. The interrupted videos appeared randomly. For the other half of the participants in a group, the other 50% of the videos were interrupted. Participants had to read aloud as many words as they could. The video continued after this task, yet having skipped 5 s of the scene. Each latent hazard had a time frame in which the latent hazard could have materialized. In group 1 the video reappeared 2 s before the time frame of the latent hazard started, in group 2 the video reappeared 4 s before the start of a time frame of a latent hazard, and in group 3 the video reappeared 6 s before the onset of the time frame of the latent hazard.

There were three dependent variables: eye fixations on the latent hazard - recorded by means of an eye tracker device - ,keys pressed when latent hazards were present (the so-called marked hazards), and the recall of the latent hazards immediately after each video clip. The results show that participants in group1 (2 second before hazard) fixated on fewer latent hazards in the interrupted videos than they did in the uninterrupted videos. This was not the case for group 2 (4 seconds before the hazard) and group 3 (6 seconds before the hazards). More or less the same pattern emerged from the key pressing data. Participants in group 1 marked fewer latent hazards by pressing a key during the interrupted videos than in the

uninterrupted videos. This did not occur with participants in groups 2 and 3. Finally, there were no statistically significant differences between recall of hazards in the interrupted videos and the uninterrupted videos in groups 1, 2 and 3. Memory effects could have influenced the results of the recalled hazards. The results indicate that situation awareness for latent hazards is briefly diminished after completion of a short, secondary task.

As this study was a laboratory experiment, the results do not legitimate any measure in relation to automated vehicles, the roads on which they drive and the 'drivers' of these automated vehicles. For evidence-based measures regarding transition of control, a follow-up study is required. This follow-up study could be a simulator study in which the (simulator) vehicle drives fully automated on large road sections. In this recommended experiment, participants should wear a head-mounted eye tracker. They would have to resume manual driving at the end of these road sections. After having switched to manual driving a latent hazard would occur in the scenario: the planned moments of transition of control. Unexpected moments of transition of control would also occur, as a result of supposed equipment failure, for instance. Differences in the human-machine interface that prepare driver for the driving task directly before resumption of control might constitute an independent factor in this recommended simulator study.

Contents

1. Introduction

1.1. Transition of control

Automation of the driving task will be beneficial for road safety, because automated systems do not speed, do not drive under the influence of psychoactive substances, never get tired, et cetera. However, as long as vehicles are not all of them fully automated and will never fail, vehicle automation may also have some negative effects on road safety. These negative effects may occur, for instance, when drivers have to switch to manual driving while in traffic because of a system failure, or when the system cannot master specific traffic situations, or only functions on particular road sections. The switch from being driven to manual driving is called ‘transition of control’ (Willemsen, Hogema & Stuiver, 2014).

1.2. Why could transition of control have negative effects on road safety?

Drivers in highly automated vehicles tend to engage in more non-driving activities than manual drivers (Carsten et al., 2012). They also tend to be less vigilant or even fall asleep when driving in a highly automated vehicle (Omae et al., 2006). When drivers do not fully have to attend to the driving task because many or all aspects of the driving task are automated, loss of situation awareness may occur (Barnard & Lai, 2010). Loss of situation awareness due to lack of attention is often referred to as the ‘out-of-the-loop problem’. Situation awareness refers to a process that generates a situation model through three stages or levels: (Level 1) perception of elements in the environment, (Level 2) comprehension of their qualities and relevance to current goals, and (Level 3) projection of their locations in space and time (Endsley, 1995). In plain English: ‘‘knowing what’s going on so you can figure out what to do”. Drivers are in the loop when they are involved in the driving task, being aware of the vehicle status, their own status and the status of the road and traffic situation. By contrast, out-of-the-loop performance means that drivers are not immediately aware of their vehicle and the road and traffic situation, because they are not actively monitoring, making decisions or providing input to the driving task (Kienle et al., 2009). Loss of situation awareness due to having been out of the loop will probably be more problematic in fully automated vehicles than in highly automated vehicles, because drivers are likely to become more out of the loop when they do not have to drive at all. In this study it has been investigated whether there are indications that situation awareness diminishes immediately after ‘drivers’ have switched from ‘driving’ in the full automatic mode to manual driving mode. This is relevant, because situations will always occur in which the ‘driver’ of the fully automated vehicle has to take over the driving task, as long as the automation cannot handle every driving condition or automated driving is only possible on certain road sections.

More than three decades ago, Lissane Bainbridge was the first to point out that although automation serves many purposes, including road safety, there are some aspects that could negatively influence safety (Bainbridge, 1983). These possible drawbacks can occur when it is the task of the driver to supervise automated systems that normally function well without human intervention, yet, occasionally, and sometimes unexpectedly, require the driver to make decisions and to act in non-standard conditions (e.g. when the system fails). She called these drawbacks the ironies of automation. One of these ironies is that drivers lose their practical skills because they rarely actively drive anymore. Automated systems tend to fail in difficult circumstances. Therefore, the driver has to use his impaired skills (due to a lack of experience) in mostly difficult circumstances. Another irony is that drivers have to monitor the system while nothing happens while driving in the automated mode. In these circumstances, it is difficult to remain vigilant and to notice irregularities that require decision-making by the driver. Hancock (2013) wrote: “If you build a system where people are rarely required to respond, they will rarely respond when required.”

Not only loss of skills and inattention may cause problems, but also the time it may take for drivers to adjust to the active driving mode. Experienced drivers are assumed to execute the driving task without much mental effort. When experienced drivers drive in a basic driving simulator while their brain activities are recorded by equipment for functional Magnetic Resonance Imaging (fMRI), Magneto Encephalography (MEG), or for Positron Emission Tomography (PET), no increased activity is found in the Prefrontal Cortex (PFC) of the brain (e.g. Bowyer et al., 2009; Calhoun et al., 2002; Callan et al., 2009; Fort et al., 2010; Horikawa et al., 2005; Mader et al., 2009). The PFC is the part of the brain that is situated directly behind the forehead. The PFC consists of various areas and is essential for the so-called executive functions. These functions regulate planning and social behaviour in situations when ‘automatic’ responses are inadequate, as in the case of planning tasks, weighing risks or other tasks that require conscious decision-making. Drivers can probably drive without involvement of the PFC, because they have developed so called ‘schemata’. According to Shallice (1988), a schema is a basic-level, mental representation of a sequence of well-learned actions. They help carrying out tasks when particular circumstances arise. When, for example, a driver approaches an intersection with the traffic light turning red, the schemata for braking when a traffic light turns red will be activated and will help the driver to perform the sequence of actions more or less automatically. The schemata that control steering a car require visuospatial and manual processing systems and appropriate recognition systems. Connected low-level schemas constitute high-level schemata. These high-level schemata are mental structures that organize our knowledge and enable us to make assumptions about things we perceive. They help us cope with situations in daily life with little mental effort. If we had to think about everything we do all the time and had to weigh all possible actions continuously before deciding to do something, we would soon be exhausted. Schemata influence our selective behaviour, as we are more likely to notice or react to things that are anticipated by our schemata. Incorrectly activated low-level schemata or not well-elaborated high-level schemata can lead to a misinterpretation of the situation. On their highest level, schemata are 'scripts' (Abelson, 1981; Schank & Abelson, 1977). One such script could be 'the-driving-on-a-motorway' script. This script is a conceptual structure of how to behave (stereotypic sequences of action, e.g. driving in the same direction as the other vehicles at a relatively high speed) and what to expect (e.g. no passengers crossing the road, no oncoming vehicles) when driving on a motorway.

Given these driver characteristics, the transition of control from automatic to manual mode could be problematic for various reasons. Drivers have to deal with a sudden change in workload. They may also have to direct their attention from other activities, unrelated to driving, to the driving task, and they may have to increase their mental efforts because their arousal level was low while not driving (Flemisch et al., 2014). It may be another cause for problems during transition of control when drivers first have to reactivate the proper schemata before they can predict what could happen and be aware of the possible hazards in road and traffic situations. So far, most studies have focussed on the mental effort aspects of transition of control (Gold et al., 2013; Merat & Jamson, 2009; Merat et al., 2014), whereas no studies have addressed the impact of the transition of control on identification of potential hazards. For this reason, this study addresses this issue, focussing on the question: Can it be assumed that, directly after drivers have resumed manual control, their hazard perception capabilities are temporarily impaired, as a result of all the relevant schemata not having been immediately activated?

1.3. What is known about transition of control and what is not known?

Regain of control after automated driving takes time. For instance, it takes some time before the driver's scanning patterns and steering corrections stabilize after having resumed the driving task (Merat et al., 2014). Drivers also brake later when a lead vehicle suddenly brakes directly after having resumed the driving task (Merat & Jamson, 2009). An overview of what is known about transition of control is presented in SWOV report R-2015- 22 “Transition of control in highly automated vehicles” (Vlakveld, 2015). However, a lead vehicle braking in close following situations constitutes an acute danger, requiring immediate action such as braking hard or swerving. There are also non-acute dangers that may or may not materialize. Such latent hazards can be other road users who are not on collision course but may start to act dangerously due to the circumstances. A pedestrian who may suddenly cross the road to catch the bus that has stopped on the other side of the road is an example of such a latent hazard. A latent hazard can also be possible other road users on collision course who are hidden from view, because the view on these road users is blocked by objects, such as large vehicles, parked cars, buildings, trees, bushes, et cetera (Crundall, 2016). When, for instance, a driver passes a bus at a bus stop, the driver has to be aware of possible (but not yet visible) passengers who have left the bus and may cross the road just in front of the bus. Drivers constantly have to detect cues to recognize situations and to predict what may happen in the immediate future in order to anticipate possible hazards. These skills are known as hazard perception skills (Vlakveld, 2014). It is assumed that experienced drivers are able to do this remarkably fast, because experience has provided them with elaborated schemata that are activated while driving (Menon & Uddin, 2010).

Hazard Perception (HP) can be defined as situation awareness for dangerous situations in the traffic environment (Horswill & McKenna, 2004). Based on the theory of situation awareness by Endsley (1995), HP is defined as the ability to detect (level 1) and recognize (level 2) possible hazards and to predict (level 3) how these possible hazards can develop into situations in which a crash is very likely. It is important to note that HP is about possible hazards that may materialize and not about sudden hazards that require immediate action (e.g. braking hard or swerving) in order to avert a crash at the very last moment. The research question formulated is:

how long does it take before risk awareness for latent hazards returns to baseline levels after transition of control.

1.4. This study

The present study is a laboratory experiment. The choice for a laboratory experiment was made because the intention was to measure situation awareness for latent hazards as accurately as possible and to exclude the impact of confounding factors as much as possible. It was investigated whether drivers are less capable of detecting latent hazards after having been fully interrupted in scanning the roadway in front for a short period, without the need to manually control the vehicle. Therefore, participants did not have to resume manual control in a fully automated vehicle while in traffic. Neither were they required to do this in a driving simulator.

The hypothesis is that after even a short interruption of the scanning task, drivers will detect fewer latent hazards and that it will take some time before their hazard perception capabilities will have been fully recovered.

When support for this null hypothesis is found in the present study, an obvious follow-up study will be a driving simulator study in which a fully automated vehicle is simulated and participants have to resume manual control after much longer periods than the short interruptions in the present study.

2. Method

2.1. The stimuli

The test consisted of 13 different animated video clips ‘filmed’ from the perspective of the driver. These video clips lasted between 28 and 41 seconds (*M* = 33.9 seconds, *SD* = 4.2 seconds). Each video clip contained a so-called high-priority latent hazard. Everything can happen, even situations that no one can predict. However, high-priority latent hazards are traffic situations that experienced and alert drivers recognize as situations that have a rather high likelihood to develop into acute threatening situations, despite their harmless appearance at first sight. See the *Appendix* for a brief description of the high-priority latent hazard in each video clip. A panel of driving examiners developed the scenarios for the video clips and selected the high-priority latent hazards (see for how this was done: Vlakveld, 2014). The hazards in the video clips did not materialize. This means that in the end no visible other road users acted in such a way that an acute threatening situation occurred and no possible other road users suddenly appeared on collision course from behind the object that blocked the view. Each video clip had a control version, in which the full video clip was displayed, and an experimental version, in which an interruption task was presented before the onset of the high-priority latent hazard. The interruption task consisted of a list of 21 short words presented on the screen. The words were derived from a 4th grade spelling exercise. In each video clip, participants first saw a plan view on the screen, lasting 3 seconds, showing the manoeuvre performed by the ‘camera car’. Next, a white screen with a black circle in the centre was presented during 2 s. It was the purpose of this screen to fixate the gaze of the participants on the centre of the screen immediately before the start of the video clip. Following this screen, the actual video clip started. At a certain moment in time during the experimental version of the video clip, a screen with words appeared for 5 s. The video clip was resumed, yet it had skipped 5 seconds after the last moment before the interruption.

Each high-priority latent hazard of a video clip came with a time frame in which latent hazard could have materialized. The interruption always ended before the onset of the time frame of the latent hazard. In addition to the control version, three experimental versions were developed.

1. A version in which the time between the end of the interruption and the start of the time frame was 2 s;
2. A version in which this gap between the end of the interruption and the onset of the time frame was 4 s, and
3. A version in which this gap was 6 s.

Directly after each video clip, a screen appeared inviting participants to activate the microphone. Subsequently, a screen appeared with two questions: “Were there any moments when you thought ‘I hope that ‘this’ will not happen?” and “If so, can you describe this or these situation(s)?” After having provided their answers, participants deactivated the microphone and started with the next video clip. See *Figure 1* for a schematic overview.

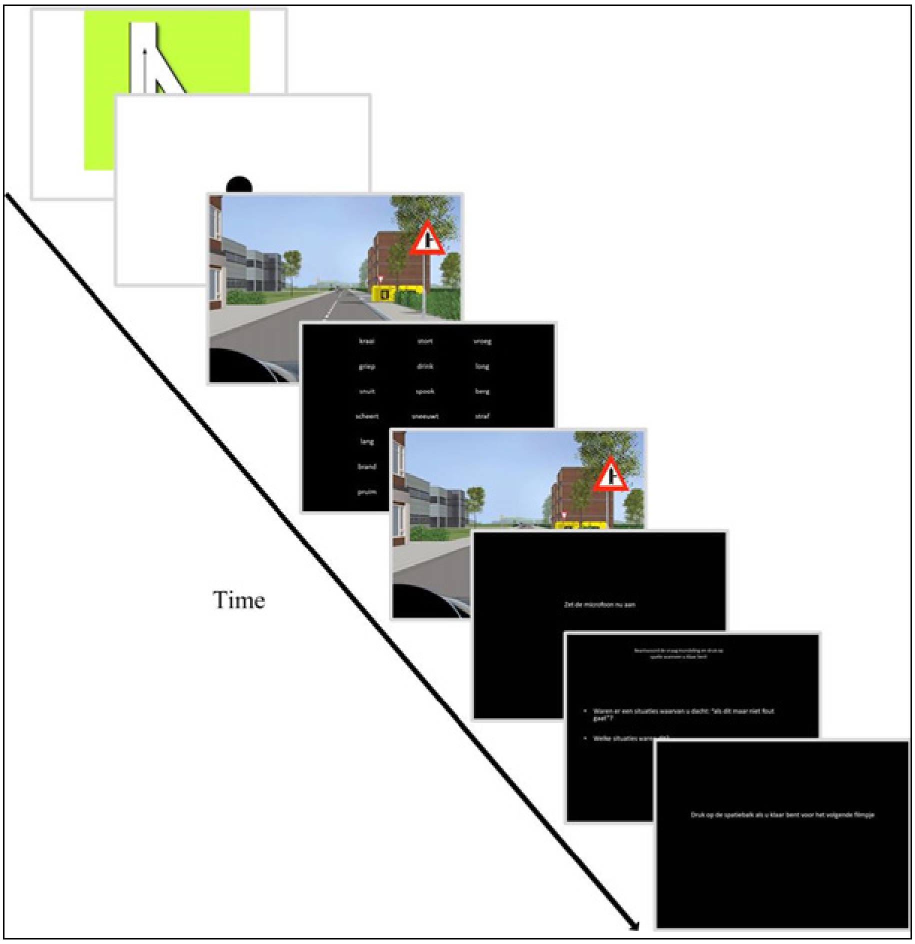

Figure 1*. Schematic overview of an experimental version (with interruption) of a video clip.*

2.2. Procedure

There were three groups of participants: The ‘2-second group’ in which, in the experimental versions of a video clip, the interruption ended 2 s before the onset of the time frame of the high-priority hazard, the ‘4-second group’ in which the experimental version of a video clip the interruption ended 4 s before the onset of the time frame of the high-priority hazard of a video clip, and the ‘6-second group’ in which, in the experimental version of a video clip the interruption ended 6 s before the onset of the time frame of the high-priority latent hazard. The video clips were always presented in the same order and in three blocks (two blocks of four and one block of five video clips). Each participant watched each video only once. Half of the video clips watched were experimental video clips (with an interruption) and the other half were control video clips (without an interruption). Within each group, half of the participants watched the experimental video clips 1, 2, 5, 8, 10, 11, and 13, and the other half within each group watched the experimental video clips 3, 4, 6, 7, 9, and 12.

In the lab room, participants were first asked to fill in an informed consent and a short demographics survey. This was followed by a PowerPoint presentation about the test. In this presentation, participants were instructed to detect two types of hazards: overt latent hazards and covert latent hazards. Overt latent hazards were explained as ‘situations in which another road user could start to behave dangerously due to the circumstances’. Covert hazards were explained as: ‘situations in which the environment gives cues about possible road users on collision course who may not be spotted because the view may be blocked by parked cars, large vehicles, trees, bushes, houses and suchlike’. The participants were explicitly asked to report no other than these two types of hazards. Participants were informed that video clips could contain more than one hazard, or no hazards at all. This was done to make sure they did not decrease performance after detecting a hazard, or tried extra hard to find a hazard in every video clip.

It was explained to the participants that their gaze directions were recorded while they watched the videos. It was also explained to them that they had to press a button in front of them at moments they felt a hazard could develop and release the button when they thought that the threat was over. They were also instructed to read out loud as many words as they could when an interruption appeared and to mention the latent hazards after each video clip, using the microphone.

After the introduction, participants completed two practice trials, one containing no interruption, and one with an interruption, after which there was an opportunity for them to pose questions about the task.

Once they indicated that they were ready to do the test, the eye tracker was calibrated to their eyes and the first block started. Calibrating the eye tracker lasted no more than approximately 60 s. After each block the eye tracker was recalibrated.

After completion of the test, participants were rewarded with a €25 gift voucher. The entire procedure lasted approximately 90 minutes.

2.3. Device

The fixations of the participants were recorded with a Gazepoint GP3 eye tracker. This eye tracker is a remote eye tracker that is attached underneath a monitor. The sample rate of the eye tracker was 60 Hz. The monitor was a 21.5’ flat screen LCD monitor (aspect ratio 16:9) placed on a table. For responses, participants needed to press a dedicated key on a keyboard. The video clips were presented full screen and the resolution was set at 1280 × 720 pixels. The frame rate was 25 fps. The average distance from the eyes of the participants to the centre of the screen was approximately 60 cm, providing them a horizontal visual field of approximately 74°.

2.4. Participants

In order to recruit participants, folders were distributed among households in the The Hague area. In addition, the Royal Dutch Touring Club (ANWB) recruited employees and members. Inclusion criteria were an annual mileage of at least 10,000 km, more than five years' driving experience, not older than 65 years of age, and normal vision or vision corrected to normal with contact lenses. Participants wearing glasses were excluded because it is difficult to calibrate the eye tracker when participants wear glasses. The ethical committee of SWOV approved of the test protocol.

Participants were randomly assigned to a group. The groups were:

- *The 2-second group:* N = 48, 65% male, mean age = 42.75 (*SD* = 10.74). When the eye tracker data was analysed, 6 of the 48 candidates were excluded due to missing eye tracker data,
- *The 4-second group*: N = 22, 68% male, mean age = 42.82 (*SD* = 9.11);
- *The 6-second group*: N = 20, 45% male, mean age = 46.15 (*SD* = 10.89).

2.5. Design and data analysis

A 3 x 2 mixed model was applied, with group (2-second, 4-second and 6-second group) as independent between-subjects factor; interruption/no interruption as independent within-subject factor; and fixation at the latent hazard, key press within the time frame of the latent hazard, and recall of the latent hazard directly after each video clip as three dependent factors.

Use was made of three different dependent factors because there is no single factor that can fully guaranty whether a latent hazard is anticipated or not. A fixation on a latent hazard not necessarily implies that the participant has detected and recognized the latent hazards. Fixations can be either bottom-up or top-down (Hahn, Ross & Stein, 2006). A fixation as a result of visual salience is called bottom-up and a fixation because of cognitive salience is called top-down. For the detection and recognition of latent hazards, only top-down fixations are relevant. In order to distinguish between the two, most of the latent hazards did not appear straight ahead and most of the latent hazards were covert hazards. In order to detect a covert hazard, participants have to gaze in directions were nothing special can be seen (no visual salience) but where an invisible road user may be expected. In case of fixations on these areas, it is very likely that these are top-down fixations. However, it is always possible that these fixations are random bottom-up fixations. Because of this uncertainty, key presses and hazard recall were also used. However, these two additional dependent variables have their weaknesses as well. In case of recall after a video clip, the latent hazard can be forgotten. Because a latent hazard never developed into an acute threatening situation and the detection and recognition of a latent hazard can be subconscious, it is very likely that latent hazards will be forgotten very soon. Another problem is that recorded spoken words have to be interpreted. No inter-rater reliability test was conducted. In case of a key press, it is not clear whether the key was pressed because of the latent hazard or because of something else. In some of the video clips, the latent hazard was present at moments when (none threatening) actions of other road users occurred as well.

The software of the eye tracker allowed for defining Areas of Interest (AOI's) in the video clips. Within the time frame of a latent hazard an AOI was constructed for each video frame. A time frame started at the moment the first cue of a latent hazard became visible and ended when it was considered as too late for evasive action to avoid a crash, should the latent hazard have materialized. The onset of an AOI was defined as the first moment visual cues became available that could provide information about a possible hazard. For example, when a road was hidden from view by bushes, the whole road behind the bushes was covered with an AOI. The AOI changed size per video frame.

The time of the first fixation in the AOI was recorded, as well as total gaze duration in the AOI. Only gazes longer than 200 ms were used for analysis because shorter fixation durations are considered to be too short for the recognition of hazards (Velichkovsky et al., 2002). A gaze duration of more than 200 ms on the AOI of the high-priority latent hazard was scored as 1; in other cases the score was 0. When predefined words were mentioned that described the latent hazard, the recall of a hazard was scored as 1 and otherwise as 0. The times the key was pressed was recorded by the software of the eye tracker. When the key was down at any moment within the time frame of the latent hazard, key press was scored as 1, in other cases as 0.

The differences were considered statistically significant when $p < 0.05$. Besides significance of the results, the effect sizes were calculated. In case of t-tests and their non-parametric equivalents, Cohen's *d* was calculated. For Cohen's *d* an effect size of 0.2 to 0.3 is considered as "small", around 0.5 as "medium" and 0.8 to infinity as "large". In case of analyses of variance, partial èta squared (partial $\eta^{2)}$) was calculated. When partial èta squared is applied, the effect size is considered as small when partial $\eta^2 \approx 0.01$, as medium when partial $\eta^2 \approx 0.06$, and as large when partial $\eta^2 \approx 0.14$ (Cohen, 1988).

3. Results

This chapter contains the results, differentiating between latent hazards that were fixated or not in interrupted videos and uninterrupted videos for the 2-second group, the 4-second group, and the 6-second group. The second dependent factor was the mentioning of the latent hazard after each video clip. These are the recalled latent hazards. This chapter also presents the results of the recalled latent hazards after uninterrupted videos and interrupted videos for the 2-second, 4-second, and the 6-second group. Finally, this chapter contains the results that indicate whether the key was pressed during any moment of the AOIs of the latent hazards in interrupted videos and uninterrupted videos for the 2-second group, the 4-second group, and the 6-second group. These are the marked latent hazards. The scores of the tasks are presented as ‘average percentages’. One has to keep in mind that these values do not represent the proportion of participants as percentages usually do, but the means of the scores of participants in a group. All the t-tests mentioned in this chapter are paired-samples t-tests. When the paired samples in a group did not meet the criteria for parametric testing, the Wilcoxon Signed Rank Test was applied.

3.1. Fixations

Figure 2 presents the results of the percentage of AOIs of high-priority latent hazards that were fixated longer than 200 ms in the three groups in the uninterrupted condition and in the interrupted condition.

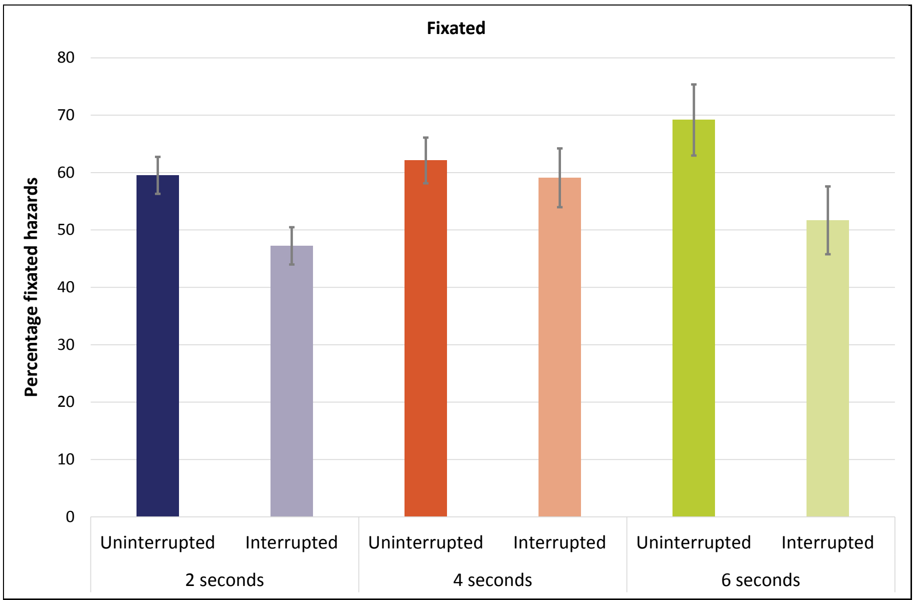

Figure 2. *Percentage fixated latent hazards per group in uninterrupted video clips and interrupted video clips. Error bars indicate +/- 1 standard error.*

In the 2-second group participants fixated on average 59.52% (*SE* = 3.22) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was 47.22 (*SE* = 3.25). A Wilcoxon Signed-ranks test indicated that more latent hazards were fixated in the uninterrupted condition than in the interrupted condition, Z = 2.355, *p* = 0.019, Cohen's *d* = 0.383.

In the 4-second group participants fixated on average 62.12% (*SE* = 3.98) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was 59.09 (*SE* = 5.11). A Wilcoxon Signed-ranks test indicated that the difference in scores was not significant, Z = 0.491, *p* = 0.623, Cohen's *d* = 0.121.

In the 6-second group participants fixated on average 69.17% (*SE* = 6.20) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was 51.67 (*SE* = 5.91). A Wilcoxon Signed-ranks test indicated that the difference in scores was marginally significant, Z = 1.704, *p* = 0.088, Cohen's *d* = 0.427.

This supports the hypothesis that there is a brief period directly after interruption in which scanning for latent hazards is impaired. However, the capability of scanning for latent hazards seems to be recovered within 4 s. No marginal decline in scanning capabilities after 6 s was expected.

3.2. Recalled latent hazards

Figure 3 presents the results of the percentages for recalled latent hazards directly after each video clip for the three groups in both the interrupted and the uninterrupted condition.

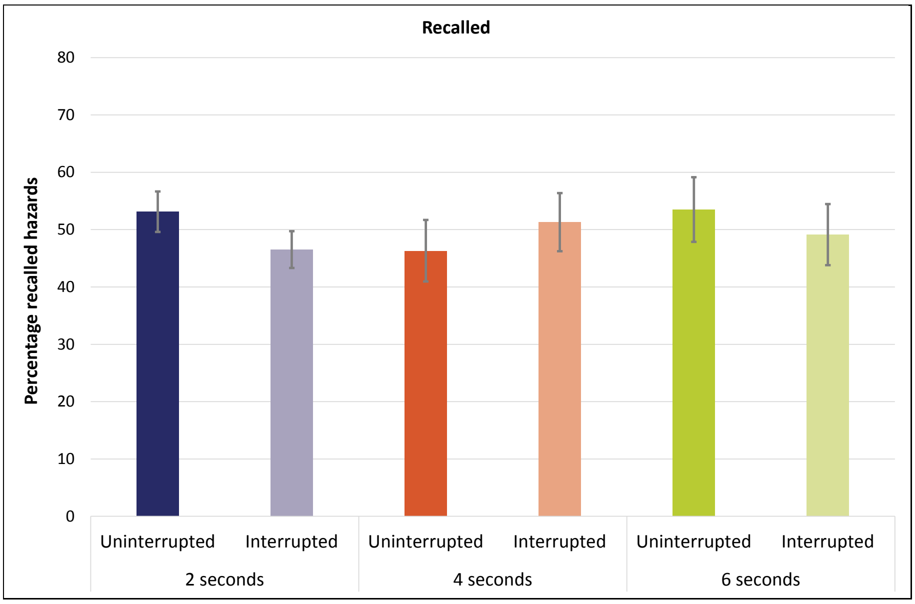

Figure 3*. Percentage recalled latent hazards per group in uninterrupted video clips and interrupted video clips. Error bars indicate +/- 1 standard error.*

In the 2-second group participants recalled on average 53.13% (*SE* = 3.53) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was 46.52 (*SE* = 3.21). A paired-samples t-test indicated that the difference between the two conditions in this group was not significant, *t*(47) = 1.403, *p* = 0.167, Cohen's *d* = 0.203.

In the 4-second group participants recalled on average 46.32% (*SE* = 5.37) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was 51.30 (*SE* = 5.07). A paired-samples t-test indicated that the difference between the two conditions in this group was not significant either, $t(21) = -0.770$, $p = 0.450$, Cohen's $d = -0.164$.

In the 6-second group participants recalled on average 53.51% (*SE* = 5.64) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was 49.12 (*SE* = 5.33). A paired-samples t-test indicated that the difference between the two conditions in this group is also not significant, $t(18) = 0.610$, $p = 0.550$, Cohen's $d = 0.148$.

These results on recall do not support the null hypothesis that there is a period with diminished hazard perception capabilities directly after interruption.

3.3. Marked latent hazards

Figure 4 presents the results of the percentages of the marked latent hazards for the three groups in both the interrupted condition and the uninterrupted condition.

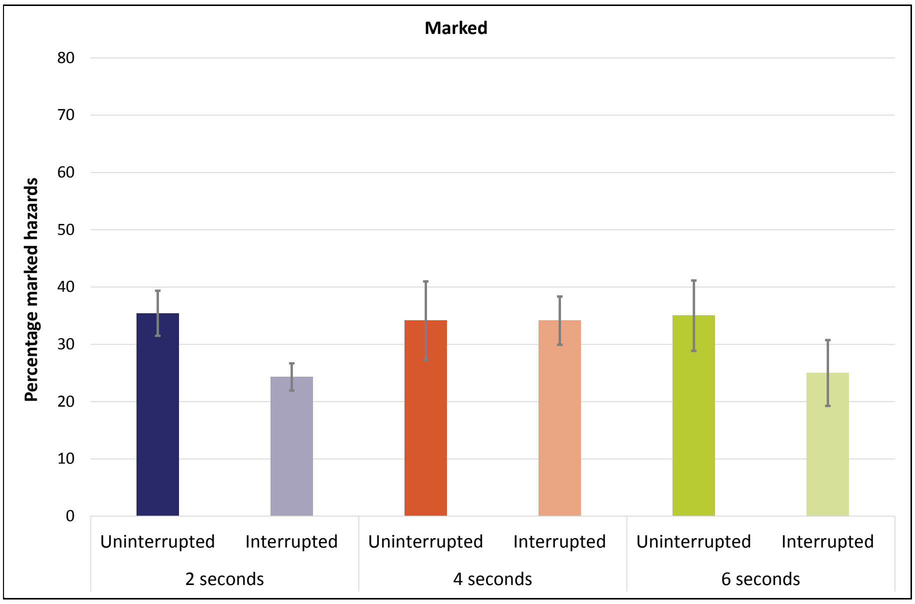

Figure 4. *Percentage marked latent hazards per group in uninterrupted video clips and interrupted video clips. Error bars indicate +/- 1 standard error.*

In the 2-second group participants marked on average 35.42% (*SE* = 3.93) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was 24.31 (*SE* = 2.38). A Wilcoxon Signed Rank Test indicated that the difference between the two conditions was significant, $Z = 2.332$, $p = 0.020$, Cohen's $d = 0.344$

In the 4-second group participants marked on average 34.13% (*SE* = 6.85) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was also 34.13 (*SE* = 4.22). There is no difference between the two conditions and therefore there can be no statistically significant difference.

In the 6-second group participants marked on average 35.00% (*SE* = 6.15) of the latent hazards in the uninterrupted videos. For the interrupted videos in this group the percentage was 25.00 (*SE* = 5.74). A paired-samples t-test indicated that the difference between the two conditions in this group was not significant, $t(19) = 1.255$, $p = 0.225$, Cohen's $d = 0.281$.

The results of the marked latent hazards show the same pattern as the results of the fixated latent hazards. However, the percentages are much lower. Presumably, some latent hazards merit a fixation but are considered as such low risk factors that they do not merit a key press. Just as the fixations, the results of the marked latent hazard indicate that there is a short period of diminished situation awareness directly after interruption, but situation awareness seems to be fully recovered within 4 s.

3.4. The groups and correlations between the three dependent variables

Comparison between the results of the 2-, 4- and 6-second groups requires that there are no significant differences in the results of the groups with regard to the baseline condition. The baseline conditions were the uninterrupted video clips. These video clips were the same for the participants in the three groups. Three analyses of variance with respectively the percentages of fixated latent hazards, the percentages of recalled latent hazards, and the percentages of marked latent hazards in the uninterrupted condition as the dependent factor, and group as the between-subjects factor, showed that there were no significant differences across the three groups, Fixated, $F(2, 87) = 1.43$, $p = 0.25$, partial $\eta^2 = 0.03$; Recalled, $F(2, 86) = 0.64$, $p = 0.53$, partial $\eta^2 = 0.03$; Marked, $F(2,86) = 0.015$, $p = 0.99$, partial $\eta^2 = 0.00$.

Table 1 shows the correlations between the three dependent factors in the baseline condition.

	Fixated		Recalled		Marked	
Fixated	–		0.183		0.151	
Recalled			–		0.365	***
Marked					–	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table1. *Pearson Correlations between the dependent factors.*

There is only a rather weak yet significant correlation between recalled latent hazards and marked latent hazards. In this study, three different dependent factors were measured, because, theoretically, whether drivers have perceived latent hazards or cannot be based on fixations alone, as a fixation on a latent hazard does not always imply necessarily that the latent hazard has been indeed recognized. In order to reduce the possibility that fixations on latent hazards were merely based on visual salience, all high-priority latent hazards in the video clips were either covert latent hazards or overt latent hazards that did not develop directly in front on the roadway ahead. As recalled latent hazards and marked latent hazards could represent aspects of hazard recognition other than fixations, weak correlations between fixated latent hazards and recalled latent hazards and fixated latent hazards and marked latent hazards do not automatically imply that recalled latent hazards and marked latent hazards are no adequate dependent factors to measure situation awareness for latent hazards.

4. Discussion

4.1. What do the results indicate?

It was hypothesized that directly after interruption of the scanning task, the hazard perception abilities would be temporarily impaired. If support for this hypothesis were found, this would indicate that after switching to manual mode, it not only takes time for drivers to control the vehicle (Merat et al., 2014) and to adequately respond to acute dangers (Gold et al., 2013; Merat & Jamson, 2009), but that the ability to *predict* potentially dangerous traffic situations, the so-called latent hazards, would be temporarily impaired as well.

The results of this study mostly support the hypothesis. The most important dependent factor was the eye fixations on areas where a hazard could develop. The results indicate that there are fewer fixations on areas of latent hazards immediately after the interruption when the gap between the end of the interruption and the beginning of the time frame of the latent hazard is two seconds. However, with a four-second gap, hazard perception no longer seems to be impaired. However, oddly enough, hazard perception seems to be impaired again when the gap is six seconds, although in the 6-second group, the difference between fixated latent hazards in the uninterrupted condition and the interrupted condition and the difference in marked latent hazards in the uninterrupted condition and the interrupted condition, were only marginally significant. A possible explanation could be that because in our experiment the interruption was short (only five seconds), the driving schemata may not have been fully deactivated the moment the scanning task is resumed (Altmann & Trafton, 2002) and that the scanning mode for reading was not immediately abandoned once the traffic scene had reappeared. Participants in the 2-second group may not have fixated latent hazards because they were still in the reading mode. Participants then switch to the automatic scanning mode for driving on the basis of the still activated schemata from before the interruption (this would explain that there are no differences in the 4-second group). However, a little bit later they realize that something has happened and switch from routine scanning for hazards to error-prone conscious scanning (Vlakveld, 2011). This may impair hazard perception again for a while and would explain the lower scores in the interrupted condition in the 6-second group. This explanation is conceptual and definitely requires more research. Moreover, this explanation is not fully supported by the results of the marked latent hazards, As for the fixations, marked latent hazards were significantly lower in the interrupted videos for the 2-second group, but there were no significant differences between the two conditions in the 4-second and the 6-second groups. Another cause for the somewhat unexpected results in the 6-second group could be the small sample size and the somewhat different composition of this group. The 2-second and 4-second groups included more men than women and the 6-second group included more women than men.

The recalled latent hazards show a different pattern altogether. There were no differences in the percentages of recalled latent hazards and marked latent hazards in the two conditions (uninterrupted/interrupted) across the three groups (2-second group, 4-second group, and the 6-second group). An explanation could be that recalled latent hazards differ from fixated latent hazards and marked latent hazards because the responses are not made at the very moment of the occurrence of the latent hazard. On the one hand, latent hazards could easily be forgotten, because the latent hazards did not materialize and no risky situations actually occurred, on the other hand, the possibility of reflection before an oral response after a video clip may have resulted in the mentioning of latent hazards that were not explicitly ‘felt’ at the moment of the latent hazard.

Situation awareness for latent hazards was measured in three different ways, fixations on latent hazards, recalled latent hazards at the end of each video clip, and a pressed key at any moment when the latent hazard could materialize (the ‘marked’ latent hazards). Only a rather weak yet significant correlation was found between recalled latent hazards and marked latent hazards. The pattern of the scores across the three groups was very similar for fixated latent hazards and marked latent hazards. Although the pattern of the scores was quite similar, considerably fewer latent hazards were marked than fixated. It seems that latent hazards probably merit a fixation mainly subconsciously and are not considered risky enough to merit a consciously made key press. Of the three dependent factors, recalled hazards factor is the only one that did not show any significant differences in the two conditions across the three groups. Possibly, both memory failure and the ability to reflect on what has just been watched may fail to make this dependent factor sensitive enough to measure short-lasting impairments in situation awareness for latent hazards.

4.2. Limitations of the study

The experiment was laboratory experiment. The rationale to conduct a laboratory experiment was to control for confounding factors. If participants had to resume driving as well, speed and the lateral position would not have been the same for all participants. Subsequently, the occurrence of latent hazards would also have differed between participants. However, watching video clips that are suddenly interrupted by a reading task does not resemble the transition from being driven to manual driving in real traffic all that much. The interruption period may have been too short; participants did not have to resume controlling a vehicle, and the horizontal view while watching video clips on a 21.5’ monitor is different from the horizontal view of drivers in a vehicle.

4.3. Implications and further research

Support was found for the existence of a period of at least 2 seconds of reduced situation awareness for latent hazards directly after transition of control.

As such, this is not enough to legitimate any measures in relation to automated vehicles, the roads on which they drive and the ‘drivers’ of these automated vehicles. The latent hazards in the scenario are the planned moments of transition of control However, it has to be kept in mind that the present study was intended as a proof of concept and not as an experiment the results of which allow for evidence-based measures.

In order to take evidence-based measures regarding transition of control; a follow-up study is required. This might consist of a simulator study in which the (simulator) vehicle drives fully automated on large road sections. In this recommended experiment, participants wear a head-mounted eye tracker. They would have to resume manual driving at the end of these road sections. Unexpected moments of transition of control will also occur when drivers have to switch to manual driving, for instance because of supposed equipment failure. Differences in the human-machine interface that prepare drivers for the driving task directly before resumption of control may constitute an independent factor in this recommended simulator study.

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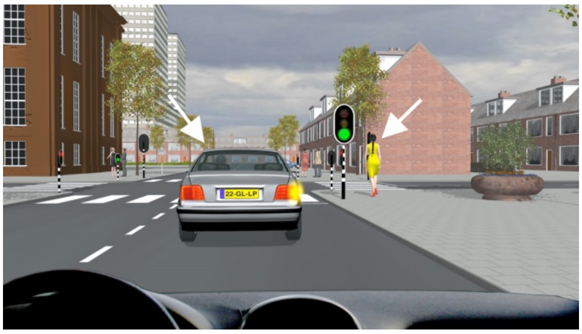
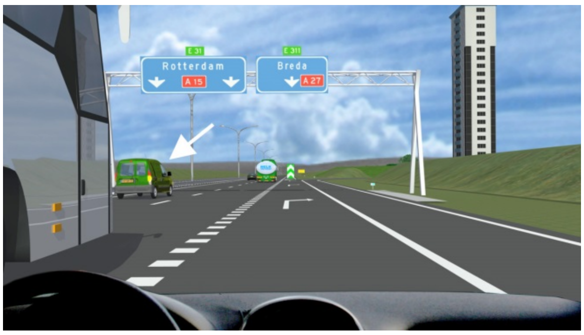
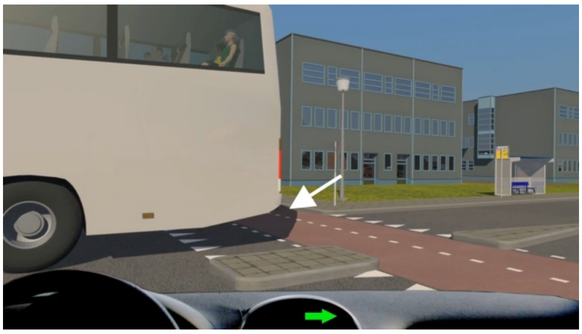
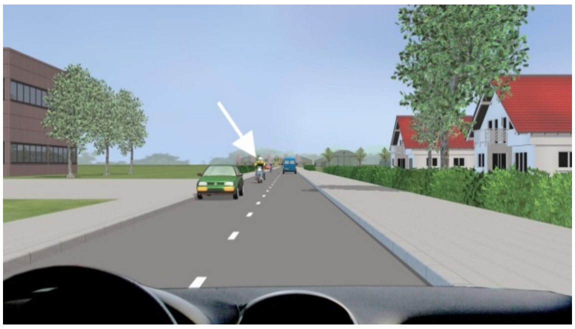
Appendix Latent hazards in video clips

Screen captures and descriptions of the latent hazards. The white arrow in the screen captures point to the latent hazard.

	**Video clip 1 (covert latent hazard)** The camera car continues straight ahead. The yellow containers at the corner block the view on possible traffic from the right. Although the camera car has right of way, possible traffic from the right may turn into the road.
	**Video clip 2 (overt latent hazard)** The camera car approaches an intersection and wants to continue straight ahead. The lead vehicle indicates to turn right. If the pedestrian crosses the road and the lead vehicle has not noticed the pedestrian, the lead vehicle will abruptly brake while turning to the right. When the camera car has not kept sufficient headway, a collision is inevitable.
	**Video clip 3 (covert latent hazard)** The camera car continues straight ahead. The blue van is parked just before the pedestrian crossing. A possible pedestrian from the right who cannot be seen because of the parked van, may cross the road. The speed of the camera car is so low that the woman has crossed the road when the camera car has reached the pedestrian crossing.
	**Video clip 4 (overt latent hazard)** The camera car is leaving the motorway. The bus to the left continues straight ahead and drives slower than the camera car. The green van has just passed the bus and indicates to move to the right. This van may move one lane to the right but could also have decided to leave the motorway at the very last moment. If it is the latter, the van may cut off the camera car.

	**Video clip 5 (covert latent hazard)** The camera car turns to the right and crosses a two-way bicycle track. The bus to the right is slowly turning to the left. This bus is blocking the view on possible bicyclists from the left.
	**Video clip 6 (overt latent hazard)ad** The camera car follows the lead vehicle rather closely. The traffic sign to the right indicates that mopeds have to continue their trip on the two-way bicycle path to the left. Mopeds have to cross the road where this is indicated on the road. There is a moped just before the van. This moped was visible in the beginning of the video clip. When the moped suddenly crosses the road, the van has to brake and the camera car may hit the van.
	**Video clip 7 (covert latent hazard)** The camera car continues straight ahead. The bus turns to the left and is blocking the view on oncoming traffic that may turn to the left at the intersection and on pedestrians that may cross the road from the left to the right.
	**Video clip 8 (overt latent hazard)** The camera car overtakes the lorry, and a woman on a bicycle rapidly approaches on the left. She may not see the driver and continue to turn onto the road.

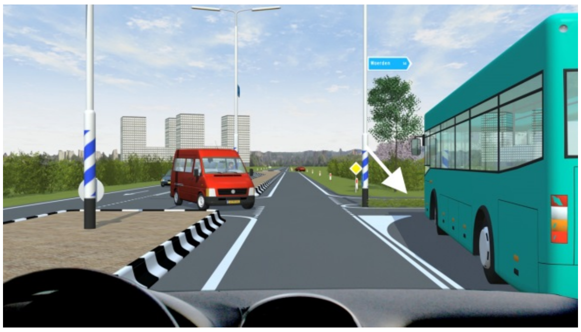
Video clip 9 (covert latent hazard)
The camera car turns to the left. The opposing lorry wants to turn to the left too but waits for the camera car to turn to the left first. The lorry blocks the view of possible oncoming traffic in the lane to the right of the lorry.



Video clip 10 (overt latent hazard)
The camera car continues straight ahead. The opposing green car has stopped and has turned on the hazard warning lights. Behind the green car a motorcycle is approaching rapidly. The motorcyclist may overtake the green car when this no longer is possible because of the approaching camera car.

Video clip 11 (covert latent hazard)
The camera car overtakes a bus. The bus has stopped at a bus stop. Passengers who have left the bus may cross the road just in front of the bus and not take the effort to cross the road at the pedestrian crossing ahead.

Video clip 12 (covert latent hazard)
The camera car is overtaking the lorry that has stopped. Earlier in the video clip could be seen that a tractor is about to enter the road from the right. This tractor may enter the road in front of the lorry.

	**Video clip 13 (covert latent hazard)** The camera car continues straight ahead. The red van has stopped. The green bus is slowly turning to the right. The bus blocks the view on possible traffic approaching the intersection from the right. Although the camera car has right of way, traffic from the right may turn into the road.