How is driving related attention in driving with visual secondary tasks controlled?

Evidence for top-down attentional control

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Abstract

We assume that in driving with visual secondary task, attention is mainly controlled through top-down processes, which direct attention to previously selected, driving relevant parts of the environment. At the same time, explorative perception is assumed to be minimized. In a driving simulation study, the phenomenon of change blindness is used as a method to asses the focus of attention. In drives with defined and controlled situational circumstances, the hypothesis is studied that in driving with visual secondary tasks, drivers direct their driving related attention primarily to driving relevant parts of the scene. The participants repeatedly approached intersections. During the approaches, a gaze pattern typical for driving with a visual secondary task was experimentally created through occlusion. Change blindness was measured for driving relevant as well as driving irrelevant vehicles. Results for N=16 subjects showed influence of relevance on the amount of change blindness. Furthermore, when first experiencing a situation with unexpected behaviour of other vehicles, attentional failures with severe consequences for driving safety occurred.

Keywords: Driving, distraction, change blindness

INTRODUCTION

Driving with visual secondary tasks

With the increasing number of technical systems which have found their way into modern vehicles, extensive research has been performed on the distraction effects of interacting with in-vehicle devices while driving, e.g. using cell-phones, route guidance systems or entertainment systems. The main reason for that area of research is that performance and safety decrements in the driving task may occur due to the distraction. For instance, distraction can lead to a decrease in lateral control (e.g. [1]; [2]; [3]; [4]), higher variations in speed (e.g. [3]; [5]; [6]), higher steering effort (e.g. [2] [7]) and delayed reaction times to sudden events (e.g. [1]; [8]).

Secondary tasks which require visual attention are especially known to interfere with driving. Research in this field led to the description of a stable gaze pattern, which can be seen in drivers engaging in visual secondary tasks while driving. The drivers repeatedly switch their gaze between the driving task and the secondary task (e.g. [9]; [10]; [11]). The number of glances directed to the secondary task depends on the type of secondary task: more complex and visually demanding tasks require more glances ([12]; [13] [9]; [14]; [15]). Aside from this, durations of single glances are rather independent of task demands and normally endure for less than 2 seconds ([16]; [17]). Between glances directed to the secondary task, drivers repeatedly look back to the driving scene ([11]). These glances are normally shorter than those away from the driving scene ([18]; [19]) and make up between 20% and 50% of the total task duration ([10]).

Assumed attentional processes

Although many studies exist in which eye movement behaviour while driving with visual secondary tasks is described, less is known about the attentional processes involved. Thinking about traffic safety, it is of special interest which parts of the driving scenery are monitored within road glances and which aspects of the driving task drivers focus on. Some authors assume that while performing visual and non-visual secondary tasks, drivers mainly focus their driving related attention on the stabilization level ([20]) and engage in lane keeping and speed adaptation. Other driving tasks, like hazard perception, are supposed to be neglected ([21]; [12]).

In theories on attentional processes, bottom-up (also called exogenous) and top-down attentional processes (also called endogenous) are differentiated (e.g. [22] [23]).

- Top-down control: Attention is used as “selection for action” ([24]). Based on anticipation, attentional resources are directed to those parts of the environment that are central for the success of the current action. Related to driving, experience guides attention in such a way that necessary environmental input for driving is gathered.
- Bottom-up control: Salient cues in the environment attract attention. Bottom-up processes are by definition pre-attentive and automatic. In driving, bottom-up processes ensure that unexpected but salient stimuli (e.g. peripheral moving objects) are perceived.

Thinking about driving with visual secondary tasks, these two processes are not sufficient to explain the influence of distraction on driving. Bottom-up processes are by definition pre-attentive. Therefore it is irrelevant which task attention is directed to as long as the salient object remains somewhere in the visual field. This means that bottom-up controlled perception should continue during distracted driving. Furthermore, because top-down controlled attention is focused on those parts of the environment that are necessary to solve the task and because drivers in general solve the driving task despite distraction, basic top-down attentional processes must – at least party - continue in the dual-task situation. Since both process continue during distraction it remains unclear why distraction results in reduced driving related attention.

Experiments on top-down processes often relate to simple tasks that are performed under stable environmental conditions. Contrary to this, driving is complex and besides central action guiding elements (e.g. the lead vehicle) also other potentially relevant objects have to be perceived and integrated in the understanding of the situation. Only through the development of a broader situational model that does not only contain action guiding elements but a more general picture of the environment, does anticipation of the future situational development and foreseeing driving become possible. Based on [22] a third attentional process is added to the already described top-down and bottom-up processing:

- Explorative perception: Attention is used to create a situational model that does not only contain currently task relevant elements but is broader. Such an enriched model contains elements that might become task relevant in the future. Reaction to elements that are already included in the situational model through explorative perception are possible more quickly than to elements that are not part of the enriched situational model.

Explorative perception is not necessarily restricted to potentially relevant or otherwise task related situational elements. It can be directed to every element in the scenery and that also includes obviously task irrelevant objects. Related to driving, explorative perception can for example be used to focus on advertisement boards or the landscape.

Table 1: Attentional processes in attentive and distracted driving.

<table>
<tr><th colspan="2"></th><th>Attentive driving</th><th>Distracted driving</th></tr>
<tr><td colspan="2">Salient stimuli</td><td>+ (bottom-up)</td><td>+ (bottom-up)</td></tr>
<tr><td rowspan="2">Driving relevant stimuli</td><td>Directly guiding action</td><td>+ (top-down)</td><td>+ (top-down)</td></tr>
<tr><td>Other driving related stimuli</td><td rowspan="2">+ (explorative)</td><td rowspan="2">-</td></tr>
<tr><td colspan="2">Other objects in the environment</td></tr>
</table>

In driving with visual secondary tasks, attention is drawn away from driving and is directed to the secondary task instead. It is assumed that in that situation driving directed attention is mainly controlled through top-down processes. That means that the drivers focus on those parts of the environment that are central for driving in the given situation. This can be the lead vehicle in a car follow situation, the colour of the traffic lights while approaching a crossing or the position on the lane in a free flow situation. At the same time, explorative perception is reduced. As a consequence the driver can react to situational changes in case they are due to one of the elements that directly guide action (e.g. braking of the lead vehicle). Reactions to unexpected situational developments are more difficult because the cause of the situational change is not attended to through top-down controlled processes. At the same time explorative perception is reduced and a broader perception of the environment does not take place. This makes it more difficult to perceive unexpected situational developments while driving with visual secondary tasks.

STUDY BACKGROUND

Study question and hypotheses

The described attentional processes and the assumed influence of distraction on the impact of the three attentional processes lead to the following hypotheses:

- During distracted driving, driving related attention is focused on task relevant elements in the environment.
- Other elements that are not central to the current driving task are not attended to.
- Because bottom-up processing is assumed to be stimulus driven and automatic, salient objects can still be perceived as long as they are somewhere in the visual field.

A commonly used approach to investigate attention in driving with visual secondary tasks is eye movement analysis. As already described, these studies led to the description of the gaze pattern with which the drivers share attention between the two tasks. Unfortunately, eye movement analysis is less suited for assessing which objects are monitored in the driving scene. This is because in the driving scene multiple relevant and potentially relevant objects are close to, together on, or nearby the road ahead in the driving scene. Due to problems of measurement precision and because it can not be assumed that an object which is not fixated is also unnoticed, eye movement recording can not be used to asses which parts of the driving scene are attended to and which are not. That is why it is necessary to find another experimental approach in which an indicator that is independent of eye movement is used to measure the focus of attention.

Theoretical background of the experimental design

To explore the hypotheses, an experimental design has been developed that combines elements of the occlusion technique with elements of experiments on change blindness.

In experiments using the occlusion technique the view of the driver is covered and, thereby, visual perception interrupted for a defined period of time. The occlusion technique can be used to evaluate the interruptability of (potential) secondary tasks in driving (e.g. [25]; [26]). In this approach a potential secondary task is occluded in order to measure whether handling of the studied secondary task suffers from glances away from the secondary task (e.g. to observe the driving scene). [27] propose using a defined temporal pattern of occlusion and task presentation to evaluate the interruptability of secondary tasks in a standardized way. The used pattern should be chosen in such a way that gaze behaviour observable in driving with visual secondary tasks is mimicked. In the second implementation, not a (potential) secondary task but the driving task itself is occluded. In this way, how long the driver can look away before the driving task (e.g. the stabilization of the vehicle) deteriorates can be determined ([28]). Because the impact of distraction on driving related attention is studied, occlusion is used as a method to interrupt vision of the driving task. To mimic driving with visual secondary task the timely pattern used for occlusion resembles the gaze pattern observable in driving with visual secondary tasks.

The second central element of the developed experimental approach is the phenomenon of change blindness. The term change blindness describes the phenomenon that sudden changes of the visual scene often go unnoticed in case the change itself is masked ([29]; [30]). Without masking, sudden changes of a scene lead to motion transients that attract attention through bottom-up processes ([30]). But as soon as the change occurs during a short disruption of visual processing (e.g. through a blink or an artificial blank), top-down controlled attention is needed to detect the change ([31]). As a consequence, change blindness mainly occurs for objects that are not in the focus of attention, e.g. because they are part of the situational background or not relevant for the understanding of the scene. Changes occurring to attended elements are normally noticed while changes to unattended elements are likely to be undetected ([31]; [32]). Coming from a measurement perspective, the phenomenon of change blindness can be used to assess which parts of the environment are in the focus of attention and which are not.

METHOD

Driving simulation

To study the attentional processes in driving with visual secondary tasks an experiment was conducted in the static driving simulation in Wuerzburg (for further information see www.wivw.de). This driving simulation has the advantage of a visual field of 300° plus a rear-view mirror. The mock-up is equipped with of original vehicle parts (e.g. steering, brake and accelerator pedal). The simulation runs under the simulation software SILAB. This software allows that course sections can be linked to each other as desired. This enables the experimenter to create an experimental course that is tailored to experimental needs. For instance it is possible to approach the same intersection as often as desired in short intervals and to adapt the behaviour of the surrounding traffic on each approach.

General study design

As described, the amount of change blindness indicates whether the changed object is in the focus of attention or not. Change blindness was measured in a standardized driving situation. The drivers repeatedly approached intersections on which they had to give right of way. On each intersection, there were three trucks approaching: one from the right hand side, one from the left hand side and the third as oncoming traffic. To maintain driving safety drivers had to check whether those trucks reached the intersection simultaneously with them and , if so, had to stop at the intersection to give right of way.

On each approach, the drivers solved a visual secondary task. The task was not self-paced, rather, the switching between the driving task and the secondary task was experimentally controlled. This was done by presenting the secondary task on top of the driving scene. This meant that while the drivers were solving the secondary task, the driving scene was occluded. The design of the secondary task and the timing of displaying the driving scene and the secondary were based on a prior study conducted in the driving simulation. In that study, drivers solved a secondary task that consisted of numbers that were to be read aloud. Results showed that although only short glances back to the road of about 250 ms could be carried out during the secondary task, drivers felt confident enough to solve the secondary task even in critical driving situations ([33]). Paralleling that study, the secondary task consisted of white numbers displayed on a black background that were to be read aloud by the drivers.

During each approach to an intersection, the secondary task was first announced by an exclamation mark presented in the head-up-display. 3 seconds thereafter, the secondary task started. Now the driver could see alternately the driving scene and the secondary task. The timing of this switching was experimentally set and fixed for each approach. During the period in which the displayed scene alternated between the driving scene and the secondary task sudden changes could occur. The drivers were to react as quickly as possible on detecting a change by pressing a button on the steering wheel. Figure 1 shows the timeline of one approach to an intersection.

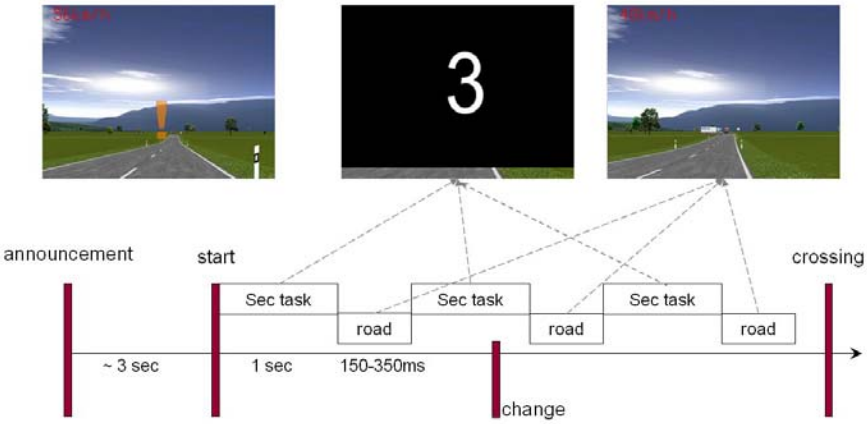

Figure 1: Timeline of one approach to an intersection.

The start of the announcement, the start of the secondary task and the trigger for the change were set in relation to points on the route. Contrary to that, the switch between the sight conditions during a given secondary task period was time dependent. To ensure that the temporal sequence was as comparable as possible between all drivers and all approaches, the participants drove with the cruise control set at 60 km/h. They could only brake (e.g. to stop at the intersection), but not accelerate above the set speed limit.

The drivers were instructed that maintaining driving safety was of the highest priority, followed by the secondary task. Of the lowest priority was the detection of the changes. The total course consisted of 60 approaches to intersections. On 17 approaches no change happened. Five approaches were used for a special situation in which the vehicle approaching as oncoming traffic changed lanes and approached the driver frontally on his own lane. To avoid a collision, the driver had to change onto the left lane to evade the oncoming truck. This type of situation was included to remind the driver that all vehicles in a situation might be relevant for driving safety.

Experimental manipulation

To analyze the focus of attention, it is necessary to compare the amount of change blindness for driving relevant vs. irrelevant objects. To ensure that the measured differences are based on relevance and not on other characteristics of the changed objects (e.g. moving vs. static, size, colour) all changed objects were trucks moving on the right or left hand side of the intersection. The truck approaching as oncoming traffic was never changed. Relevance was defined as being dependent on speed and direction of the crossing trucks. It is assumed that vehicles with which the driver could potentially collide in the near future are relevant. Figure 2 shows the manipulation of relevance graphically.

- Vehicles which are going to reach the intersection simultaneously with the driver are believed to be relevant.
- Vehicles approaching the intersection so slowly that they reach the intersection after the driver has already passed are potentially relevant.
- Vehicles moving away from the intersection are irrelevant.

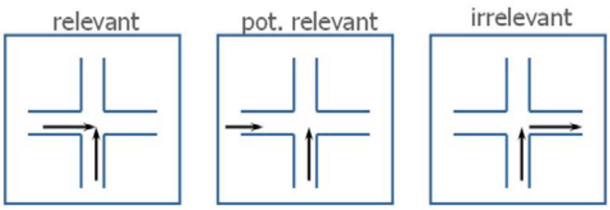

Figure 2: Manipulation of relevance. The ego-vehicle is approaching from the bottom. Only one of the three crossing trucks is shown.

Different types of changes were implemented: the changed truck could either jump or disappear. All the results presented in this paper are based on disappearing vehicles only.

Furthermore, the duration of the display of the road was varied. The road was displayed for 150 ms, 250 ms or 350 ms. 250 ms were chosen based on the measured glance times in a prior experiment [33]; 350 ms are close to what is reported in other studies on gaze behaviour while driving with visual secondary tasks; 150 ms are extremely short and it is of interest whether drivers are still able to react appropriately with such short glance times. The duration of the occlusion (that is of the secondary task presentation) was kept constant at 1 second. During one approach, only one of the three durations of road glances was used.

As a last factor, the time of the change was manipulated. The changes either occurred during one of the periods in which the road was visible (road display) or while the secondary task was shown (occlusion). The changes in the condition occlusion could happen anytime during the occlusion (because the change was masked anyway), in the condition road display it was set that the changes should happen at the beginning of a road glance, meaning between 70 ms and 90 ms after the start of the road glance. Based on what is known from other experiments on change blindness, unmasked changes should be noticed better because of bottom-up attentional processes. In combination with factor relevance this assumption leads to the prediction of an interaction: Changes to relevant objects should be noticed independent of the time of change because top-down controlled attention is directed to them. For irrelevant objects, unmasked changes should be noticed better than masked changes because of bottom-up processes. The factor time of change was the only one that was manipulated as a between factor.

Table 2: Experimental design.

	Duration of road display	**Vehicle disappears**		
		rel.	pot. rel.	irrel.
Group 1: road display	150ms			
	250ms			
	350ms			
Group 2: occlusion	150ms			
	250ms			
	350ms			

Study sample

N=16 subjects participated in the study. They were randomly assigned to one of the two experimental conditions (road display vs. occlusion). The mean age of participants was 28 years (sd=5.0 years) with n=9 male drivers. The test drivers were selected from a test driver panel of the WIVW. All drivers had completed at least 3 hours of practice in the driving simulation ([34]) and had mostly participated in several other driving simulator studies before.

Data recording and analysis

The recorded data included all input of the driver (e.g. steering, braking, button presses), parameters of the secondary task and the occlusion, information on the surrounding traffic as well as parameters of the driving environment (e.g. position on lane). All parameters were recorded with 120 Hz. The main parameter analyzed is the percentage of detected changes.

For the situation “frontal vehicle” driver reaction was coded online by the experimenter. It was noted whether a collision occurred, whether a tight situation evolved or whether the situation was solved safely.

RESULTS

Manipulation check

The changes during road display took place between 66 ms and 94 ms (mean = 78 ms) after the road display started. The distance between the changed vehicle and the ego-vehicle at the time of change was calculated. Figure 3 shows the distance in degrees between the further path of the ego-vehicle and the position of the changed vehicle at the time of the change. As can be seen, that distance is higher for the irrelevant vehicles.

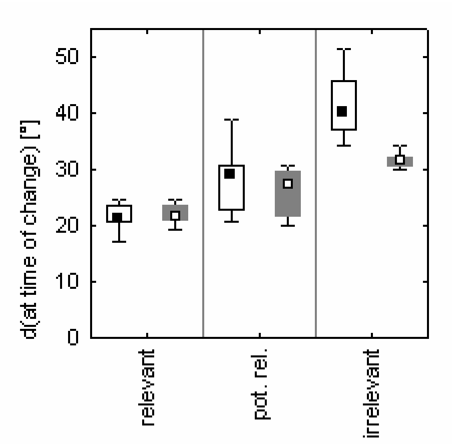

Figure 3: Distance between the further path of the ego-vehicle and the position of the changed vehicle at the time of the change. Median, middle 80% of the distribution and area without outliers are given in the graph.

Situation "frontal vehicle"

Figure 4 shows the reaction of the drivers in the situation "frontal vehicle". The five situations implemented in the course are listed in order of occurrence. It can be seen that in the first occurrence of the situation, 12 out of 16 drivers are not able to solve the situation safely. After having experienced the situation once it is no problem for the drivers to solve the following situations safely. The number of collisions or tight situations drops to 3 out of 16 even in only the second rehearsal of the situation. The accumulation of critical situations in the first rehearsal of the situation is significant (X^2 = 43.6, df = 10, p < 0.001).

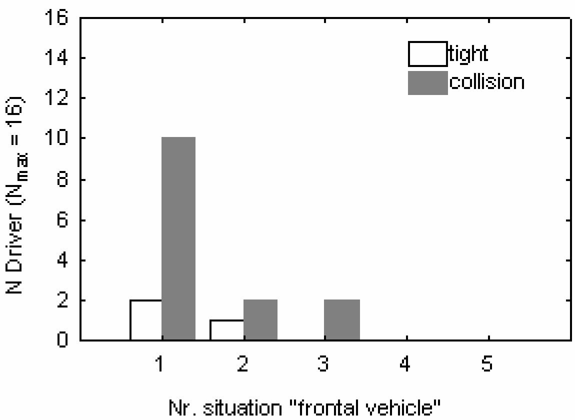

Figure 4: Number of collisions and tight situations in situation "frontally approaching vehicle".

Analysis of change blindness

Figure 5 shows the influence of relevance and time of change on the percentage of correctly detected changes. The great difference between changes of relevant and potentially relevant objects to irrelevant ones is obvious. For potentially relevant objects, all drivers detected all changes. The consequence of this is that that condition has to be excluded from the analysis due to lack of variance. For relevant objects, about 97% of the changes are noted, for irrelevant ones only about 23%. The two-factorial ANOVA shows a significant effect of relevance ($F(1,14) = 103.1$, $p < 0.001$; based on relevant and irrelevant only) and no effect of time of change ($F(1,14) = 0.3$).

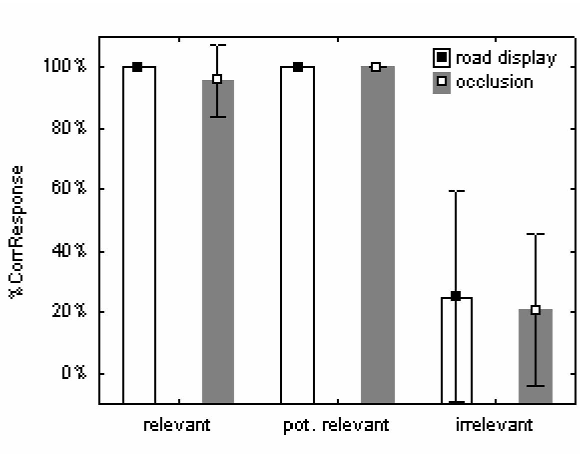

Figure 5: Influence of relevance and time of change on the amount of detected changes. Means and standard deviations are given in the graph.

In a second analysis the factor duration of the road glances is tested together with the factor relevance. Again potentially relevant objects are excluded from the analysis because of lack of variance. Results show the already observed main effect of relevance ($F(1,14) = 61.35$, $p < 0.001$), a nearly significant main effect of duration ($F(2,28) = 3.00$, $p = 0.066$) and a significant interaction ($F(2,28) = 5.47$, $p < 0.01$). The interaction is due to the effect that the difference between relevant and irrelevant changes is only nearly significant for 150 ms ($p = 0.07$), whereas for the two other durations the influence of relevance is significant ($p < 0.01$).

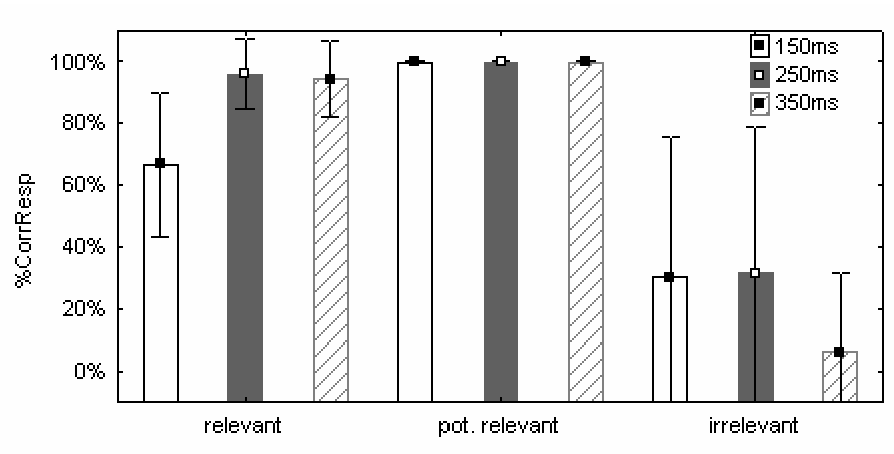

Figure 6: Influence of relevance and duration of road glances on the amount of detected changes. Means and standard deviations are given in the graph.

DISCUSSION

As expected, the relevance of the changed object for the driving task strongly influences the amount of change blindness. The effect is so strong that, in the condition potentially relevant objects, all drivers detect all changes. Unexpectedly, the manipulation relevant vs. potentially relevant objects did not have any effect. Both types of changes are more or less equally well perceived, those for potentially relevant objects even a bit better. This effect is probably due to the fact that drivers have difficulties anticipating precisely the future course of moving objects. That is why they cannot differentiate whether they will meet with another crossing vehicle at the intersection or whether that vehicle will pass after them. Therefore, relevant and potentially relevant vehicles are subjectively of the same relevance. One the other hand, the irrelevant vehicle already passed the intersection at the time the secondary task started. So it is obvious that this vehicle is no longer relevant for driving.

As shown in the section on the manipulation check irrelevant vehicles did not only differ in driving related relevance from the other vehicles but also in distance to the intersection at the time of change. Therefore it can not be completely ruled out that the effect of relevance is an effect of distance. This explanation seems highly unlikely because a slight enlargement of distance would lead to a large drop in detection rate. Nevertheless, in follow up studies care should be taken that the distance to the driver at the time of change is better controlled.

Contrary to the expectation that bottom-up processing should take place also in the studied dual task condition, changes occurring during road glances are not noticed better than occluded ones. Results from change blindness experiments show that unmasked changes are generally perceived well because of salient motion transients. There are two possible explanations in our context why change blindness also occurs for unmasked changes:

1. Bottom-up processing is reduced during dual task situations. This explanation would be in line with results on the phenomenon of the attentional blink. Directly after switching from one task to the next, bottom-up attentional processes like pop-out effects are reduced ([35]). The length of this effect is

influenced by the demands of the task ([36]) prior to switching and endures up to 500 ms ([35]). These results indicate that bottom-up processes might be not completely pre-attentive. Therefore, it might be that not only explorative perception but also bottom-up processes are reduced during driving with visual secondary tasks.

2. Cues that are salient and lead to bottom-up processing in static experimental settings are not necessarily salient in the driving context. The motion transient that result from a disappearing object might be salient on a static background (like mostly used in experiments on change blindness) but not in a driving context with ego-movement and simultaneous movement of other objects.

To test which of the two explanations is true, it is necessary to a baseline-condition without a secondary task include in follow-up experiments. In that condition, it can be checked whether the used changes are salient and lead to bottom-up processing in undistracted driving. If that is the case, the missing effect in the dual-task condition is due to the distraction. Otherwise it would be interesting to test which types of changes are salient in the driving context, because results found in other settings obviously could not then be transferred easily to driving.

The small effect of the duration of the road glance shows that the top-down controlled monitoring of task relevant objects is a highly efficient process. Even with very low glance times of 150 ms, the drivers are able to detect disappearing potentially relevant and relevant vehicles in most of the cases.

From the perspective of traffic safety the situation frontal vehicle is of central interest. On the first rehearsal of the situation, 12 out of 16 drivers perceived the frontally approaching truck too late to solve the situation safely. The strong learning effect shows that this is not because the oncoming danger is difficult to see. Coming back to the three assumed attentional processes, the drivers could not react appropriately because the unusual situational development was not part of their situational model. That is why they focussed their attention top-down on other, subjectively more relevant parts of the scenery. At the same time, explorative perception was minimized. Under those circumstances it becomes very difficult to perceive unexpected situational developments. After first experiencing the unusual behaviour of the approaching vehicle, that possibility was included in the situational model. From now on, the drivers were able to perceive the approaching vehicle early and to solve the situation safely.

The experimental results show both the advantages and the dangers that come along with the attentional strategy of relying on top-down control during driving with visual secondary tasks. As long as situational changes are due to the top-down selected and therefore monitored aspects of the situation, the drivers can react appropriately. In those situations the top-down attentional control is a highly efficient process to monitor the situational development during distraction. But as soon as the situation changes in an unexpected way, attentional failures become likely. Because drivers focus on those parts of the situation that are believed to be most relevant, changes occurring due to other objects are neglected. As it can be seen in the situation frontal vehicle, in that case even severe attentional failures (e.g. looked-but-failed-to-see-errors [37]) become possible and can lead to severe driving errors.

The theoretical background chosen can explain the known vulnerability of young drivers to vehicle crashes caused by distraction ([38]; [39]). For instance, a study by [40] showed that young drivers more often divide their attention between driving and secondary tasks inappropriately. Based on the assumed processes, reduced or incomplete mental models of the driving scene are the main cause for these results. Due to their inexperience, young drivers are more vulnerable to misjudging driving situations. Therefore, they are more likely to start secondary tasks in inappropriate situations and to monitor the wrong elements in the situation during driving with visual secondary tasks.

REFERENCES

[1] Törnros, J. E. B., and Bolling, A. K. (2005) Mobile phone use-effects of handheld and handsfree phones on driving performance. Accident Analysis and Prevention. 37: 902-909.

[2] Engström, J., Johansson, E., and Östlund, J. (2005) Effects of visual and cognitive load in real and simulated motorway driving. Transportation Research F. 8: 97-120.

[3] Horrey, W. J., and Wickens, C. D. (2002) Driving and side task performance: the effects of display clutter, separation, and modality. TechReport AHFD-02-13/GM-02-2. University of Illinois, Aviation Human Factors Division, Savoy.

[4] Jamson, A. H., and Merat, N. (2005) Surrogate in-vehicle information systems and driver behavior: effects of visual and cognitive load in simulated rural drivin. Transportation Research Part F. 79-96.

[5] Burns, P. C., Parkes, A., Burton, S., Smith, R. K., and Burch, D. (2002) How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol. TRL Report TRL547. TRL Limited, Berkshire, United Kingdom.

[6] Zheng, X. S., Tai, Y.-C., and McConkie, G. W. (2003) Effects of cognitive tasks on driver's eye behavior and performance. 3rd International Symposium on Human Factors in Driver Assessment, Training & Vehicle Design.

[7] Boer, E. R. (2000) Behavioral Entropy as an index of workload. IEA 2000/HFES 2000 Congress. July 29 - August 4, San Diego.

[8] Ishida, T., and Matsuura, T. (2001) The effect of cellular phone use on driving performance. International Association of Traffic Safety Sciences (IATSS) Research. 6-14.

[9] Sodhi, M., Reimer, B., and Llamazares, I. (2002) Glance analysis of driver eye movements to evaluate distraction. Behavior Research Methods, Instruments, & Computers. 34: 529-538.

[10] Victor, T. (2005) Keeping eye and mind on the road. Thesis. Universitet Uppsala, Uppsala.

[11] Wierwille, W. W. (1993) Visual and manual demands of in-car controls and displays. In B. Peacock, and W. Karwowski (eds.). Visual and manual demands of in-car controls and displays. Taylor & Francis, London.

[12] Victor, T., Harbluk, J. L., and Engström, J. A. (2005) Sensitivity of eye-movement measures to in-vehicle task difficulty. Transportation Research F. 8: 167-190.

[13] Dingus, T. A., Antin, J. F., Hulse, M. C. and Wierwille, W. W. (1989) Attentional demand reqirements of an automobile moving-map navigation system. Transportation Research A. 23A: 301-315.

[14] Tijerina, L., Kantowitz, B., Kiger, S. M., and Rockwell, T. H. (1994) Driver workload assessment of in-cab high technology devices (Paper No. 94-S2-O-

060). Proceedings of the 14th International Technical Conference on Enhanced Safety of Vehicles, München.
[15] Chiang, D. P., Brooks, A. M., and Weir, D. H. (2004) On the highway measures of driver glance behavior with an example automobile navigation system. Applied Ergonomics. 35: 215-223.
[16] Bruckmayr, E., and Reker, K. (1994) Neue Informationstechniken im Kraftfahrzeug. Zeitschrift für Verkehrssicherheit. 40.
[17] Zwahlen, H. T., Adams, C. C., and DeBald, D. P. (1988) Safety aspects of CRT touch panel controls in automobiles. Stress and Tension Control 3. Stress Management. 335-344.
[18] Rassl, R. (2004) Ablenkungswirkung tertiärer Aufgaben im PKW-systemergonomische Analyse und Prognose. Thesis. Technische Universität München, München.
[19] Schweigert, M., and Bubb, H. (2003) Einfluss von Nebenaufgaben auf das Fahrerblickverhalten. VDI-Berichte 1768, Braunschweig.
[20] Michon, J. A. (1985) A critical view of drivers behaviour models: what do we know, what should we do? In L. Evans, and R. C. Schwing (eds.). A critical view of drivers behaviour models: what do we know, what should we do? Plenum Press, New York.
[21] Schweigert, M. (2002) Fahrerblickverhalten und Nebenaufgaben. Thesis. Technische Universität, München.
[22] Hoffmann, J. (1993) Vorhersage und Erkenntnis. Hogrefe, Göttingen.
[23] Neisser, U. (1976) Cognition and reality: Principles and implications of cognitive psychology. Freeman, San Francisco.
[24] Allport, A. (1987) Selection for action: Some behavioral and neurophysiological considerations of attention and action. In H. Heuer, and A. F. Sanders (eds.). Selection for action: Some behavioral and neurophysiological considerations of attention and action. Erlbaum, Hillsdale.
[25] Baumann, M., Keinath, A., Krems, J. F., and Bengler, K. (2004) Evaluation of in-vehicle HMI using occlusion techni,ques: experimental results and practical implications. Applied Ergonomics. 35: 197-205.
[26] Noy, Y. I., Lemoine, T. L., Klachan, C., and Burns, P. C. (2004) Task interruptability and duration as measures of visual distraction. Applied Ergonomics. 35: 207-213.
[27] Lansdown, T. C., Burns, P. C., and Parkes, A. M. (2004) Perspectives on occlusion and requirements for validation. Applied Ergonomics. 35: 225-232.
[28] van der Horst, R. (2004) Occlusion as a measure of visual workload: an overview of TNO occlusion research in driving. Applied Ergonomics. 35: 189-196.
[29] Simons, D. J. (2000) Current approaches to change blindness. Visual Cognition. 7: 1-15.
[30] Simons, D. J., and Levin, D. T. (1997) Change blindness. Trends in Cognitive Sciences. 1: 261-267.
[31] Pearson, P. M., and Schaefer, E. G. (2005) Toupee or not toupee? The role of instructional set, centrality, and relevance in change blindness. Visual Cognition. 12: 1528-1543.
[32] Triesch, J., Ballard, D., Hayhoe, M., and Sullivan, B. T. (2003) What you see is what you need. Journal of Vision. 3: 86-94.
[33] Rauch, N., Gradenegger, B., and Krüger, H.-P. (2008) Das Konzept des Situationsbewusstseins und seine Implikationen für die Fahrsicherheit. Forschungsvereinigung Automobiltechnik e.v.

[34] Hoffmann, S., and Buld, S. (2006) Darstellung und Evaluation eines Trainings zum Fahren in der Fahrsimulation. In *VDI-Berichte: Integrierte Sicherheit und Fahrerassistenzsysteme* (Vol. 1960). Düsseldorf: VDI-Verlag GmbH.

[35] Joseph, J. S., Chun, M. M., and Nakayama, K. (1997) Attentional requirements in a 'preattentive' feature search task. Nature. 387: 805-808.

[36] Jiang, Y., and Chun, M. M. (2001) The influence of temporal selection on spatial selection and distractor interference: An attentional blink study. Journal of Experimental Psychology: Human Perception and Performance. 27: 664-679.

[37] Brown, I. D. (2005) Review of the 'Looked but failed to see' accident causation factor. Road safety research report No. 60. Departement of Transport, London.

[38] Ferguson, S. A. (2003) Other high-risk factors for young drivers - how graduated licensing does, doesn't, or could adress them. Journal of Safety Research. 34: 71-77.

[39] Stutts, J. C., Reinfurt, D. W., Staplin, L., and Rodgman, E. A. (2001) The role of driver distraction in traffic crashes. Washington, DC: University of North Carolina

[40] Wikman, A.-S., Nieminen, T., and Summala, H. (1998) Driving experience and time-sharing during in-car tasks on roads of different width. Ergonomics. 41: 358-372.