THE EFFECT OF COGNITIVE TASKS ON PREDICTING EVENTS IN TRAFFIC

Martin R.K. Baumann (DLR / BASt, Germany),
Tibor Petzoldt (Chemnitz University of Technology, Germany),
Chantal Groenewoud (Utrecht University, The Netherlands),
Jeroen Hogema (TNO, The Netherlands),
Josef F. Krems (Chemnitz University of Technology, Germany)

martin.baumann@dlr.de

ABSTRACT: Numerous studies demonstrate the negative effects of cognitively loading secondary tasks on driving performance. We assume that this effect is caused by interference between these secondary tasks and central executive functions of working memory that serve to keep the driver's situation model of the current traffic situation updated. In this experiment 48 drivers had to drive in a high fidelity driving simulator on a rural road while performing no secondary task, or a working memory task (auditive monitoring) that should not interfere with situation awareness, or a working memory task (memory updating) that should interfere with the comprehension and prediction function of situation awareness. While driving, participants had to react to events that were either announced by a warning signal or not. We hypothesized that participants will benefit least from the warning signal when they had to perform the memory updating task. The results generally support this hypothesis indicating that central executive functions of working memory are highly involved in situation awareness processes.

1 Introduction

There are numerous studies demonstrating the negative effects of cognitive tasks on driving performance (e.g., [1-9]). These studies generally find an increase in response latencies of drivers performing cognitively loading tasks, a decrement in lane keeping performance, or a loss of situation awareness. But these studies seldom link their findings to underlying cognitive processes. The aim of this experiment is to examine whether the effect of cognitively loading tasks on driving behaviour can be partly attributed to interference between the loading task and situation awareness processes. According to [10] situation awareness serves three functions: the perception of elements of a situation, the comprehension of these elements and their relation to the situation as a whole, and the prediction of the future development of the situation. Especially the comprehension and the prediction function draw on working memory resources. To accomplish these functions perceived information has to be associated with information stored in long-term memory to construct a knowledge network that represents the meaning of the current situation, the situation model. We will use this term synonymously to situation awareness. For this construction process knowledge has to be retrieved from long-term memory in order to be available for the associative processes. [11] assume that the prediction function is integrated within this comprehension process as in most cases a given situation is not only connected to knowledge that determines its meaning but also to expectations about its future development. These expectations are also retrieved and become part of the situation model. In non-routine situations additional attention-demanding processes are necessary to make predictions about the further development of the situation. In this case information has to be kept in working memory to be available for these processes.

Imposing cognitive load on the driver withdraws resources necessary for the comprehension of the current situation and the prediction of future development of the situation. The looked-but-did-not-see phenomenon [12] is an example of the interference of cognitive load with situation awareness. In this case the cognitive load by an additional task leads to an incomplete comprehension of one or more situation elements. This then might lead to an inappropriate action selection of the driver.

According to [13, 14] working memory is not a single structure but consists of different parts: a phonological buffer with an articulatory loop, a visuo-spatial buffer, and the central executive. Recent studies [14-16] indicate that the central executive serves different functions that seem to be highly relevant for the comprehension and projection processes of situation awareness as described above. One of these central executive functions is the retrieval of information from memory, a process essential in the comprehension process of situation awareness. Another is the maintenance of information in a non-modality specific buffer, the episodic buffer, and the control of working memory contents. We assume that the effect of cognitive loading tasks on driving is at least in part due to the interference of these tasks with these central executive processes. The specific aim of this experiment is to test whether specific kinds of cognitive load that are designed to interfere with specific central executive processes interfere especially with the prediction function of situation awareness.

Therefore the participants in this experiment drove through a scenario that contained both predictable and non-predictable events. These events were designed to be exactly equivalent besides that in the predictable version a warning sign warned the driver of the upcoming event. The reaction to the event when the participant was warned was compared to the reaction when the driver was not warned.

While driving the participants had to perform (i) an auditory monitoring task that should not load on the comprehension functions of the central executive, or (ii) a running memory task that should heavily load on those central executive functions that are involved in the comprehension and prediction function of situation awareness, or (iii) no secondary task. In the monitoring task participants had to react as fast as possible to an auditory signal that was presented with either after a long or a short time interval after the previous signal. By using only two randomly presented interstimulus intervals this tasks induces a strong tendency for rhythmic responding leading to errors, mainly too early responses. To avoid these errors one has to constantly suppress rhythmic tapping. According to [17] this task should tap the monitoring function of the central executive. But as this function should not be strongly involved in the construction process of situation awareness this task should interfere less with the construction of a situation model. Therefore the monitoring task should interfere less with the prediction of events in traffic than the running memory task.

In the running memory task [18] participants are presented with a constant stream of items and they have to remember the last items, for example the last three items. As the participants do not know when the stream ends and therefore do not know when they are asked to recall the last presented items, this task requires that the set of items kept in working memory is constantly updated. That is, each time a new item is presented it has to be encoded in working memory and the “oldest” item has to be removed from working memory. Performing this task directly involves those central executive functions that control working memory content, i.e. those functions that should also be highly involved in maintaining and updating a proper situation model. Therefore, this task should interfere with situation awareness processes and especially with the prediction function of situation awareness. We assume therefore that this updating of working memory is highly interfering with the comprehension and the projection function of situation awareness.

To summarize, we assumed that participants driving the scenario without performing a secondary task should clearly benefit from the warning signs in the predictable events. The benefit from warning signs should be reduced when participants had to perform an additional task while driving. And the reduction of this benefit should be greater when participants had to perform the running memory task than when they had to perform the monitoring task, as the memory task should interfere more with the comprehension and prediction function of situation awareness than the monitoring task.

2 Method

2.1 Participants

48 participants took part in this experiment. Their age ranged from 21 to 58 with a mean of 36.9 years (SD = 12.1). Of these participants 29 were male. All participants possessed a valid driving licence at least for one year and drove at least 10000 km per year.

2.2 Driving scenario

The experiment was run in the high fidelity driving simulator of TNO in Soesterberg, Netherlands. The driving scenario consisted of driving on a rural road with an approximate speed of 80 km/h. Each drive took about 20 min. During a drive each participant encountered four critical events. In all of these events the participant's lane was blocked by an obstacle, for example by a construction site. In two of these events the driver was given information to predict the obstacle, for example a warning sign next to the road; in the other two the driver did not receive such warning information. Each participant drove the scenario only once.

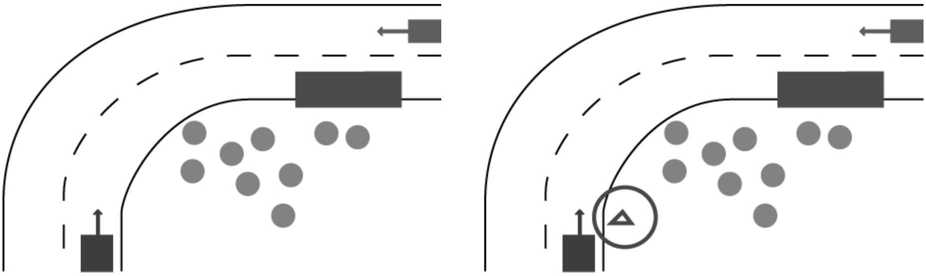

Fig.1. Sketch of the basic layout of the critical events; left side non-predictable obstacle on the lane as no warning sign was presented, right predictable obstacle with warning sign (marked by triangle)

2.3 Secondary tasks

In each secondary task condition participants had to perform several trials of the respective task. The trials lasted between 20 and 40 sec, and were followed by a no secondary task phase (where participants only had to drive) also lasting between 20 and 40 sec. Start and the end of a secondary task trial were triggered when the participant passed a certain position on the road. Therefore it was guaranteed that the participants in the secondary task conditions encountered the critical events while performing the respective secondary task.

2.3.1 The monitoring task

In the monitoring task participants had to react as fast as possible to an acoustical signal consisting of a short, clearly audible sound. As response device a finger switch was used that was applied to the index finger of the participant’s dominant hand. The time interval between two successive signals was either 1 or 2 sec, randomly chosen. We measured the participants’ response times and the numbers of errors, predominantly early responses.

2.3.2 The running memory task

In the running memory task participants were presented an audio stream of 13 possible letters, presented with a frequency of 1 letter per 2 sec. The participants’ task was to repeat the current last three letters each time a new letter was presented. For example, assume the letters “S”, “P”, and “Q” were already presented and the next letter was “G”, the participant had to repeat loudly “P Q G”, after presentation of “G”, and after the next letter “M”, the participant had to repeat “Q G M”, and so on. After a variable amount of time (20 to 40 sec) an acoustical signal was presented to inform the participant about the end of the current trial. After that the last repeated triple of letters was taken as the participant’s response in this trial. This response was taken to measure the participant’s accuracy in this task.

2.4 Design

In this experiment two independent variables were manipulated: the type of secondary task (no secondary, monitoring task, running memory task) and the predictability of the critical event (predictable, non-predictable). The secondary task factor was manipulated as between-subjects factor. Therefore the whole sample of 48 participants was divided into three groups with 16 participants each. The predictability factor was manipulated as within-subjects factor. Each of the participants encountered both predictable and non-predictable events during his/her drive. This results in a 3 (secondary task) x 2 (predictability) mixed factorial design.

As dependent measures we used different aspects of the driving performance to characterize participants' reaction to the critical events, such as Time to Collision at the time of response begin or maximum brake pressure after the obstacle became visible. Also, driving performance in phases without critical events was recorded to allow for the assessment of the effects of the secondary task performance on normal driving. Additionally, the participants were asked to rate their workload when performing each task while driving using the Rating Scale for Mental Effort (RSME, [19]). We also measured the participants' secondary task performance and eye movement behaviour but describing the analysis of these measures is beyond the scope of this paper.

3 Results and Discussion

We will only present an overview of some critical results of this experiment. These results focus on the driver's reaction to the obstacle on the lane after it became visible to the driver (see Table 1). After this moment there should be a clear difference in drivers' reaction between drivers that were warned of the obstacle before and were able to correctly comprehend and integrate its meaning into their situation model compared to drivers that were either not warned or not able to fully comprehend the warning signal and therefore were not able to predict the obstacle on the lane. Therefore the difference in the respective measures of drivers' reactions to events with warning signal and to the corresponding events without warning signal reflect how effective the participants in the different secondary task conditions could integrate the warning signal into their situation model and prepare themselves for the upcoming obstacle. According to our hypothesis we assume that this difference should be greatest in the no secondary task condition and smallest in the memory updating condition.

Table 1. Mean values of various performance measures

		no secondary task	monitoring task	memory updating task
TTC at first throttle release after roadblock is visible in *sec*	no sign	3.69	3.75	3.66
	sign	5.26	4.55	4.24
Speed at first throttle release after roadblock is visible in *kph*	no sign	70.23	68.77	69.21
	sign	57.62	62.86	64.45

The first measure is the Time to Collision (TTC) at the moment the driver released the throttle to brake after passing the location where the obstacle first became visible. As participants being prepared to the obstacle should have already reduced their speed after seeing the warning signal and should brake earlier than participants that did not comprehend the warning signal fully, TTC for prepared participants should be larger than for unprepared. And as stated above this difference should be greatest in the no secondary task condition and lowest in the updating memory condition. As shown in the first row in Table 1 the results confirm this prediction. Whereas the difference between the predictable and the non-predictable obstacle is 1.6 sec in the no secondary task condition, it is 0.8 sec in the monitoring task condition and 0.6 sec in the memory updating condition. This picture is confirmed in a 3 (secondary task) x 2 (predictability) mixed ANOVA. TTC is significantly greater for predictable events, $F(1, 45) = 40.78$, $p < .001$. And very important the interaction between secondary task condition and predictability is significant, $F(2, 45) = 3.86$, $p = .028$, reflecting the reduction in the difference between predictable and non-predictable events from no secondary task to monitoring task to running memory task condition. The main effect of secondary task condition did not reach significance, $F(2, 45) = 1.95$, $p = .15$.

The same picture emerges when one looks at the speed of the participants when they release the throttle to brake in front of the obstacle. First, there is not much of a difference in speed between the no secondary task condition and the two secondary task conditions in case of a non-predictable obstacle, indicating the validity of the experimental design. But there is a clear difference in speed between these conditions in case of a predictable obstacle. Participants in the secondary task conditions were driving faster when they started to brake than participants in the no secondary task condition, indicating that these participants were less prepared to the obstacle despite the warning sign. Looking at the speed difference between predictable and non-predictable obstacles the same pattern can be found as for TTC. The greatest difference in speed could be found in the no secondary task condition, 12.6 km/h, a medium difference in the monitoring condition, 5.9 km/h, and the smallest in the memory updating condition, 4.8 km/h. Again this indicates that participants in the memory updating condition had the greatest difficulties to comprehend, integrate, and react to the warning sign. A 3 (secondary task) x 2 (predictability) mixed ANOVA revealed a significant main effect of predictability, $F(1, 45) = 43.63$, $p < .001$, indicating that speed was significantly higher in non-predictable events at the time of the begin of the brake reaction. As for TTC the interaction between secondary task condition and predictability for speed as dependent measure was significant, $F(2, 45) = 4.35$, $p = .019$, confirming the reduced benefit from the warning signal from no secondary task to monitoring task to running memory task condition.

A basic problem with this kind of analysis is that the interpretation of the effects of the secondary tasks on driving performance as being due to structural differences between the secondary tasks rests on the precondition that task difficulty can be excluded as alternative cause. More specific, the greater interference between the memory updating task and the construction of the situation model should not be a result of a memory updating task that is simply more difficult than the monitoring task. Instead, the greater interference should be due to the different working memory functions both tasks involve. This argument cannot be made straight forward and easily because of the necessary differences between both tasks, especially with regard to the different performance measures – number of trials with correctly updated memory set for the memory updating task vs. number of wrong taps in the monitoring task. But there are some indications that support the interpretation of the results in terms of the structural task differences. First, we analysed lane keeping performance in curves. Previous studies demonstrated the sensitivity of this driving performance aspect to driver's cognitive load [2, 5]. As the driving task is especially difficult in curves, driving performance should be especially sensitive to differences in task difficulty between the secondary tasks. We found no differences between the tasks both with regard to standard deviation of lane position and number of lane exceedances. A second indication that both tasks were of comparable task difficulty stems from the participants' RSME ratings of workload when performing each task while driving. There was no difference in the ratings between the tasks.

These results cannot completely exclude the alternative interpretation that the greater interference between the memory updating task and the situation model construction is due to the greater difficulty of the updating task. But these results support the interpretation that structural differences between the tasks are the reason for the differential effects on situation awareness.

4 Conclusions

The aim of this experiment was to test one hypothesis about the cognitive foundation of negative effects of cognitively distracting tasks on driving performance. We assumed that such tasks load on working memory and especially on central executive functions of working memory that are also highly involved in maintaining and updating a proper situation model of the current traffic situation. Such functions are the control of working memory content, involving updating the content and removing irrelevant information from working memory, and the retrieval of information from long-term memory to comprehend encoded information in working memory. These functions are necessary to keep the situation model current and to integrate all relevant implications of observed situation elements into the situation model. If additional tasks interfere with these functions as they also require them then the risk is that some elements of the traffic situation are not fully comprehended and their implications are not integrated into the situation model. This should clearly impair the prediction function of situation awareness, that is cognitively distracted drivers should be less able to predict the future development of the current traffic situation and therefore should be less prepared to these developments.

We tested this prediction in a driving simulator experiment where participants encountered predictable and non-predictable events while driving and performing secondary tasks that specifically tapped relevant central executive functions of working memory. The results confirm our hypothesis that the central executive function of controlling working memory content is highly involved in the construction of situation awareness. Interfering with this function by a secondary task leads to a detrimental effect in the driver's ability to predict the future development of a traffic situation. This results help to clarify the cognitive mechanisms that underly situation awareness.

5 Acknowledgments

This study was funded by the Network of Excellence “Humanist” (Human centred design for information society technologies). We would like to thank Ingmar Stel from TNO for programming the driving simulation scenario, preprocessing the data according to our changing requirements and supporting this study with helpful hints. We also would like to thank Marika Hoedemaeker and Wiel Janssen from TNO for their help in designing and conducting this experiment.

6 References

[1] McKnight AJ, McKnight AS: 'The effect of cellular phone use upon driver attention'. Accident Analysis & Prevention, 1993, 25, (3), pp. 259-265

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

[3] Hancock PA, Lesch M, Simmons L: 'The distraction effects of phone use during a crucial driving maneuver'. Accident Analysis & Prevention, 2003, 35, (4), pp. 501-514

[4] Harbluk JL, Noy YI, Eizenman M: 'The impact of cognitive distraction on driver visual behavior and vehicle control', Transport Canada, 2002, Report No.: TP 13889 E.

[5] Jamson AH, Merat N: 'Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving'. Transportation Research Part F, 2005, 8, (2), pp. 79-96

[6] Nunes L, Recarte MA: 'Cognitive demands of hands-free-phone conversation while driving'. Transportation Research Part F: Traffic Psychology and Behaviour, 2002, 5, (2), pp. 133-144

[7] Salvucci DD, Macuga KL: 'Predicting the effects of cellular-phone dialling on driver performance'. Cognitive Systems Research, 2002, 3, (1-4), pp. 95-102

[8] Strayer DL, Johnston WA: 'Driven to distraction: Dual tasks studies of simulated driving and conversing on a cellular telephone'. Psychological Science, 2001, 12, (6), pp. 462-466

[9] Brown ID, Tickner AH, Simmonds DC: 'Interference between concurrent tasks of driving and telephoning'. Journal of Applied Psychology, 1969, 53, (5), pp. 419-424

[10] Endsley MR: 'Toward a theory of situation awareness in dynamic systems'. Human Factors, 1995, 37, (1), pp. 32-64

[11] Baumann M, Krems JF: 'Situation Awareness and Driving: A Cognitive Model'. in: Cacciabue PC, (Ed.): 'Modelling Driver Behaviour in Automotive Environments' (Springer, 2007), pp. 253-265

[12] Brown ID: 'Review of the "Looked but Failed to See" Accident Causation Factor'. London: Department for Transport; 2005. Report No.: 60.

[13] Baddeley A: 'The episodic buffer: A new component of working memory?' Trends in Cognitive Sciences, 2000, 4, (11), pp. 417-423

[14] Baddeley AD: 'Working Memory' (Clarendon Press, 1986)

[15] Baddeley A, Emslie H, Kolodny J, Duncan J: 'Random generation and the executive control of working memory'. Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 1998, 51A, (4), pp. 819-852

[16] Baddeley AD, Logie RH: 'Working memory: The multi-component model'. in: Miyake A, Shah P, (Ed.): 'Models of working memory' (Cambridge University Press, 1999), pp. 28-61

[17] Vandierendonck A, De Vooght G, Van der Goten K: 'Interfering with the central executive by means of a random interval repetition task'. Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 1998, 51A, (1), pp. 197-218

[18] Pollack I, Johnson LB, Knaff PR: 'Running memory span'. Journal of Experimental Psychology, 1959, 57, (3), pp. 137-146

[19] Zijlstra FRH, Van Doorn L: 'The construction of a scale to measure perceived effort'. Delft, The Netherlands: Department of Philosophy and Social Sciences, Delft University of Technology; 1985.