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Relating the detection response task to critical events – Consequences of high cognitive workload to brake reaction times

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Abstract

Currently the use of new interaction modalities with in-vehicle information systems (IVIS), for example speech interaction, leads to a shift from visual-manual workload to more cognitive workload. The aim of this study was to better determine the link between increasing cognitive workload and corresponding reaction times that are relevant to the driving task, for example brake reactions to sudden events. In a driving simulator study with 35 middle-aged participants, subjects had to remember a series of digits ranging from 2 to 5 numbers, recall them in the reverse order and additionally react to suddenly appearing pedestrians. Cognitive workload was assessed by a head-mounted detection response task (DRT). It was hypothesized that with increasing difficulty of the cognitive task, hence increasing cognitive workload, reaction times to the DRT as well as brake reaction times to the pedestrian increase. DRT reaction time increased significantly with ascending number of digits. However, increasing cognitive workload did not affect brake reaction times in this setting. One reason might be the strong salience of pedestrians as a stimulus, leading to no increase in reaction time.

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Keywords: Detection response task; Cognitive workload

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1. Introduction

The assessment of driver distraction has been an important topic for the last years in the automotive industry. In this context the focus mostly lied on visual-manual distraction caused by in vehicle information systems (IVIS). Currently cognitive workload caused by these systems becomes more important since new interaction modalities, like speech interaction, are used and valid methods to measure this kind of workload are needed. One promising approach is the detection response task (DRT). It has shown to be able to detect differences in cognitive workload reliably (Vilimek, Schäfer and Keinath, 2013 [1]). However, it is also important not only to measure the amount and change of workload, but to relate the consequences of increased workload to the driving behaviour. A possible negative outcome could be a delayed reaction to critical events relating to the driving scene. Several studies have already set their focus to potential critical situations. In some of these studies the critical stimulus was a red light that was supposed to imitate the braking lights of a leading vehicle (Consiglio, Driscoll, Witte and Berg, 2002; Irwin, Fitzgerald and Berg, 2000 [2,3]). In these basic research settings it was shown that the brake reaction time increased while having a phone call. Furthermore this kind of effect had also been found in more applied settings, when participants had to held a phone call and react to braking lights of a lead vehicle in a driving simulator (Strayer and Drews, 2004; Bellinger, Budde, Machida, Richardson and Berg, 2009 [4,5]). The aim of this study was to better determine the link between cognitive workload and even more critical driving events. Instead of the often used reaction to braking lights the corresponding brake reaction time to an appearing pedestrian was measured in a driving simulator setting to increase ecologic validity. Based on the existing literature it was hypothesized that with increasing workload the brake reaction time to the pedestrians also increases as well as DRT reaction times.

2. Method

2.1. Subjects

28 men and 7 women took part in the experiment. They were between 26 and 56 years old with a mean age of 39 years (SD = 9.5 years). All participants were employees of BMW and had experience with driving simulators to rule out simulator sickness.

2.2. Driving courses and tasks

The experiment included two driving courses. Both courses were set up in an urban environment with moderate traffic. The driving task was to perform longitudinal and lateral control on the car and to comply with the traffic rules. In both courses participants had to solve a secondary task, which was a cognitive task with increasing complexity. In particular they had to remember a series of digits ranging from 2 to 5 numbers and to recall them in the reverse order. The task was chosen from the Wechsler Adult Intelligence Scale (WAIS-IV; Petermann, F. 2012 [6]). An illustration of the chronological sequence of the sequence of 3 digits is shown in figure 1. Every new sequence was announced in advance, followed by the first digit after 2 to 4 seconds. The inter-stimulus-interval between the digits was 1 second. After the last digit there was a pause from 3 to 5 seconds followed by a sound that signaled to recall the series. Hence, the task can be separated into three phases. In the first phase participants listened to the numbers. This phase was followed by a pause where they had to reverse the series. In the third phase participants recalled the reversed series after the signal.

In one course – the DRT course – cognitive workload of the different levels of the cognitive task was measured by a head-mounted detection response task that has proved to discriminate between different amounts of workload in earlier studies (Conti, Dlugosch, Vilimek, Keinath and Bengler, 2012 [7]). Participants had to solve this task simultaneously with the cognitive task. A red LED was illuminating with in an inter-stimulus-interval of 3 to 5 seconds. By pushing a button that was fixed on the left side of the steering wheel, participants had to react as fast as possible when the light was illuminated and the response time was measured in milliseconds. Also the number of missed signals was measured. A signal was assessed as missed when no button press was measured after 2 seconds of LED onset.
Fig. 1. Chronological sequence of the cognitive task.

In the other course – the pedestrian course – subjects also solved the cognitive task in all four levels and additionally had to react to suddenly appearing pedestrians. The latter could have entered the street either from the left or from the right sidewalk and walked right in front of the car thus an immediate brake reaction was required in order to prevent a crash. They appeared in different phases of the secondary task as well as when no secondary task was running to prevent predictability. The relevant brake reaction time was measured when the pedestrian appeared in the second phase of the cognitive task, i.e. the phase between the last digit and the signal to recall the series. It was expected that – besides solving the driving task – within this time span participants should only be cognitively demanded since they neither have to listen to nor speak to anything, but to remember and reverse the series. 25 pedestrians appeared in the critical phase during the whole course with a temporal distance from 60 to 90 seconds, so five relevant brake reactions necessary in each block plus five in the baseline condition were included in the analysis. Brake reactions to pedestrian that appeared during the other phases of the cognitive task or when no sample was running were not included in the analysis.

2.3. Design

A 2x5 within-subjects-design was used in this experiment. The two courses were presented in random order. Within one course the different levels of the cognitive task were presented in separate blocks that were announced in advance by the experimenter. In addition to the four different levels of the cognitive task a baseline condition was included in both courses where participants only needed to react to the DRT light or an occurring pedestrian without doing the cognitive task. The tasks and the baseline conditions were presented in random order respectively. The experimental design is illustrated in Table 1.

Table 1. Experimental Design.

<table>
<thead>
<tr>
<th>Dependent Variable – Course / number of digits in the cognitive task</th>
<th>Base</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRT reaction time – DRT course</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Brake reaction time – Pedestrian course</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Before the experimental trials started, participants practiced every level of the cognitive task solely and with the corresponding secondary task, either the necessary brake reaction to the pedestrian or to the DRT light. After three trials of practice were solved correctly the experimental trial started. Overall, the experimental trial of the pedestrian course lasted about 35 minutes. In the DRT course the blocks lasted for two minutes and contained 6 to 9 series in each difficulty level, resulting in an overall course duration of about 10 minutes. With a break between the courses and the practice trials the whole experiment lasted for about 90 minutes. A third course was included where participants reacted to the DRT and simultaneously solved a task in the HMI of the car. This course is not part of this report. The experimental sequence for one participant can be seen in Table 2 exemplarily.

Table 2. Experimental sequence for one participant.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Familiarization with the simulator</th>
<th>Practice trial pedestrians</th>
<th>Experimental trial pedestrians</th>
<th>Break</th>
<th>Practice and experimental trial HMI</th>
<th>Practice trial DRT</th>
<th>Experimental trial DRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration in minutes</td>
<td>5</td>
<td>10</td>
<td>35</td>
<td>10</td>
<td>15</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>
2.4. Dependent variables

In the DRT course reaction times to the DRT as well as hit rate and false alarms were measured for all four levels of the cognitive task and the baseline trial. It was hypothesized that with increasing cognitive workload the reaction time to the DRT increases. In the pedestrian course brake reaction times to the pedestrian were measured and should also increase with increasing workload induced by the cognitive task. Subjective workload was assessed in both courses using one scale of the driving activity load index (DALI; Pauzié, 2008 [8]) that asked for the mental effort of a specific task. The scale ranged from 0 “no mental effort” to 5 “high mental effort”.

2.5. Equipment

A static driving simulator was used with a mockup–car and three plasma screens in front of the car.

For the head-mounted DRT a red LED was attached to a baseball cap in the peripheral field of view. The LED was set up as provided by the ISO 17488 [9], which means that it was fixated in a distance of 12cm to the left eye with a visual angle of 15 degrees to the left of the eye and 7.5 degrees over the eye.

3. Results

Mean reaction times over all participants were computed for each condition in each course and the data were subjected to an univariate ANOVA with the factor length of the series. For pair wise comparisons Bonferroni tests were used.

3.1. DRT reaction times

The mean reaction times, standard errors, number of missed signals as well as the subjective amount of workload for the DRT course is shown in table 3. As hypothesized the reaction time to the DRT stimulus increased significantly \( F(4, 128) = 34.3, p < .001 \) with ascending workload in series with more digits. Post-hoc tests revealed a significant difference between all task conditions and the baseline condition. Within task conditions, a series of 5 digits induced significant more workload than series of 2 and 3 digits. There was also an increasing workload from 2 to 4 digits. Furthermore the number of missed signals increases significantly with ascending workload \( F(2,64) = 9.2, p < .001 \). In the baseline condition significant less signals were missed than in 4 and 5 digits condition. In the 3 digits condition there were also significantly less signals missed than in the 5 digits condition.

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>2 digits</th>
<th>3 digits</th>
<th>4 digits</th>
<th>5 digits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean DRT reaction time in ms ( M )</td>
<td>438</td>
<td>527</td>
<td>543</td>
<td>567</td>
<td>591</td>
</tr>
<tr>
<td>Standard error in ms ( SE )</td>
<td>20</td>
<td>19</td>
<td>21</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Missed signals</td>
<td>0.5</td>
<td>1.2</td>
<td>0.9</td>
<td>1.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Subjective workload</td>
<td>1.1</td>
<td>1.6</td>
<td>2.5</td>
<td>3.3</td>
<td>4.4</td>
</tr>
</tbody>
</table>

3.2. Brake reaction times

The mean reaction times and standard errors to the pedestrians are shown in table 4. No significant main effect for length of the series was found concerning the brake reaction times to the pedestrians \( F(4,588) = 1.18, p = .32 \), indicating that increasing cognitive workload does not result in slower braking reaction times within this setting.
Table 4. Mean brake reaction times and standard errors to pedestrians in ms.

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>2 digits</th>
<th>3 digits</th>
<th>4 digits</th>
<th>5 digits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean reaction time to pedestrian in ms (M)</td>
<td>808</td>
<td>808</td>
<td>814</td>
<td>785</td>
<td>805</td>
</tr>
<tr>
<td>Standard error in ms (SE)</td>
<td>15</td>
<td>15</td>
<td>14</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Subjective workload</td>
<td>1.3</td>
<td>1.5</td>
<td>2.2</td>
<td>3.1</td>
<td>3.9</td>
</tr>
</tbody>
</table>

3.3. Secondary task performance

As participants always had to solve two tasks at a time (except for the baseline conditions) effects of task prioritization need to be considered. For this purpose the number of incorrect reversed series of digits was analyzed and compared between the two courses. Data are shown in table 5.

Table 5. Number and standard deviation of incorrect reversed series.

<table>
<thead>
<tr>
<th></th>
<th>2 digits</th>
<th>3 digits</th>
<th>4 digits</th>
<th>5 digits</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRT course</td>
<td>0 (0.2)</td>
<td>0.14 (0.6)</td>
<td>0.77 (1.2)</td>
<td>2.20 (2.1)</td>
</tr>
<tr>
<td>Pedestrian course</td>
<td>0 (0)</td>
<td>0.29 (0.6)</td>
<td>0.74 (1.1)</td>
<td>2.00 (1.8)</td>
</tr>
</tbody>
</table>

In each block participants had to reverse between 10 and 15 series. As can be seen in table 5 the number of incorrect reversed samples is ascending with increasing complexity (DRT course: $F(1.6, 53) = 29, p < .001$; Pedestrian course: $F(1.5, 53) = 32, p < .001$). In both courses significantly more mistakes were made in the 5 digit condition than in all other conditions ($p < .001$). Furthermore in both courses in the 4 digit condition more mistakes were made than in the 2 digit condition ($p < .05$). In the pedestrian course even the difference between the 2 and 3 digit condition is significant ($p < .05$).

4. Discussion and conclusions

The aim of the current study was to link the consequences of increasing workload to reaction times in critical traffic situations. Clearly the induction of different levels of workload with the used secondary task was shown by the increasing DRT reaction times with ascending workload that correspond to the existing literature (i.e. Vilimek et al., 2013; Conti et al., 2012; [1,7]). However brake reaction times did not increase under higher workload. To explain this finding, several aspects need to be discussed. The missing increase of brake reaction time despite of increased workload measured by the DRT seems contradictory to previous results, where higher cognitive workload led to increased reaction times to braking lights for example. One explanation for the missing increase in brake reaction time could lie in task prioritization effects. In both courses more mistakes in the cognitive task were made with ascending complexity but only in the DRT course also the reaction times increased. Participants might have been prioritizing the braking task over the cognitive task in order to handle the critical situation. The use of strategies to solve critical traffic situations adequately was shown in several studies before, i.e. when drivers reduced their speed while performing a visual secondary task (Platten, Milicic, Schwalm and Krems, 2013; Horberry, Anderson, Regan, Triggs, and Brown, 2006 [10,11]) or a cognitive secondary task (Caird, Willness, Steel, and Scialfa, 2008 [12]). Furthermore it could have been shown that drivers adapted their behavior in a secondary task in demanding situations when the task is interruptible without a loss of performance (Platten, Schwalm, Hülsmann and Krems, [13]). In the current experiment prioritization does not seem as necessary within the DRT course as nothing critical happens if participants miss a signal. Another aspect that needs to be considered is the pedestrian stimulus. Pedestrians have not been used so far and there might be a difference in the salience of it compared to braking lights, leading to faster reactions or no decrease in reaction time to the more salient stimulus, the pedestrian. Since the brake reaction to a leading vehicle might not be extremely urgent in every situation, people might show a delayed reaction but still save driving behavior because the situation stays uncritical in a certain amount of time. The appearance of a pedestrian in front of the car is a more critical event. Here an immediate reaction seems more natural and necessary to prevent any kind of accident. Furthermore analysis of distance to lead vehicles and lane
deviation could give information about possible strategies during the driving task. To get a more detailed picture of the current findings, these aspects have been considered in a follow-up study by the author where on the one hand different stimuli for the primary and secondary task were used and on the other hand an extensive range of driving data was analyzed. (Mantzke, in prep.).

References