

Distribution of visual attention during distraction: Influence of demands of the driving task and of the secondary task

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ABSTRACT

Newer studies report that drivers tend to engage with secondary tasks anytime without considering demands of the driving task. On the other hand, it is reported that driver adapt their interaction with secondary tasks to the demands of the current driving situation. One possibility of how this can be done is to adjust the distribution of attention between driving and the secondary task in accordance with the demands of the current driving situation.

An experiment is presented in which the influence of task difficulty of the secondary task as well as of the driving task is investigated. The experiment took place in the driving simulator with N=16 drivers. The participants solved two visual secondary tasks that differed subjectively and objectively in difficulty. Each experimental drive consisted of sections that differed in their situational difficulty (short term demands of driving). Furthermore, long term demands of the driving task (in the experiment fog vs. no fog) were manipulated. Results show, that in the easier task a higher proportion of button presses can be performed without looking at the display. Regarding the influence of the driving task, both, long and short term demands influence how much attention is directed to the road during distraction. In more demanding situations, a higher proportion of attention is directed to the driving task than in less demanding situations. The presented results support the assumption that drivers adapt their interaction with visual secondary tasks to the demands of the driving task.

INTRODUCTION

In the last years, more and more publications reported how dangerous interacting with secondary tasks while driving can be. From the widely cited 100-car-study (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005) naturalistic driving data is available on how many incidents or crashes occurred while the drivers were distracted by some kind of secondary task. In a test track experiment, Horrey & Lesch (2009) found that drivers interact with secondary tasks independent of the current driving situation although they were told to choose an appropriate time for attending to the secondary task. The mentioned results indicate that drivers are not able to adapt their interaction with secondary tasks to the demands of the driving situation and attend to distracting task independent of whether the current driving situation is suitable or not.

Besides such results, other studies exist which are more in line with the assumption that drivers are able to adapt their interaction with secondary tasks to the demands of the driving situation. In queries, drivers report that their decision to interact with secondary tasks depends on the characteristics of the driving situation. For instance, in a survey by Boyle & Vanderwolf (2005) one third of the drivers who in general do phone calls while

driving reported that they dial also while driving, 41% reported dialling during short period of stopping and 23% state that they purposefully stop before dialling (similar results see also Thulin & Gustafsson, 2004). Furthermore, drivers report that they do not only chose appropriate situations for telephoning but that they also adapt their driving behaviour to the distraction: for example 50% state that they reduce speed always or mostly always while talking on the phone (Thulin & Gustafsson, 2004). In an experiment in the driving simulator, Metz, Schömig, Krüger, & Bengler (2010) found that drivers adapt their interaction with visual secondary tasks to the demands of the driving situation (see also Rauch, 2009). In the study, drivers adapted the acceptance of secondary tasks to the demands of the driving situation as well as their interaction (e.g. distribution of attention) with the secondary task.

There are two different ways how drivers can adapt their interaction with distracting activities to the demands of the driving task:

1. They can purposefully choose driving situation which are stable and only little demanding to engage with distracting tasks, e.g. standing (Boyle & Vanderwolf, 2005), low traffic density (Kern, Schmidt, Pitz, & Bengler, 2007), familiar routes (Kern et al., 2007), non-critical driving situations (Metz et al., 2010; Rauch, 2009).
2. They can adapt their behaviour while interacting with the secondary task to the demands of the driving task. In principal, there are several possibilities of how such an adaptation can take place:
 - Driving can be adapted, e.g. slowing down (Metz et al., 2010; Thulin & Gustafsson, 2004), increasing distance or avoiding demanding manoeuvres like overtaking (Thulin & Gustafsson, 2004).
 - The distribution of attention while driving distracted can be adapted, e.g. more attention is directed to driving in more complex driving situations (Tsimhoni, Smith, & Green, 2004; Wierwille, 1993; Metz, 2009).
 - The execution of the secondary task can be adapted, for instance drivers may try to solve the secondary task (e.g. making button presses) while looking at the road or the secondary task is interrupted in order to focus more attention on driving (Esbjörnsson & Juhlin, 2003; Metz et al., 2010).

Like described, there are several possibilities of how demands of the driving task can influence drivers' behaviour and attention during distraction. Furthermore, not only the demands of the driving task but also the characteristics of the secondary task influence the distribution of attention during distraction. In general, during visually distracted driving, drivers repeatedly switch their gaze between the driving task and the secondary task. In the literature it is reported that more complex tasks are in general related to a higher number of off-road glances (Victor, Harbluk, & Engström, 2005; Dingus, Antin, Hulse, & Wierwille, 1989; Sodhi, Reimer, & Llamazares, 2002; Tijerina, Kantowitz, Kiger, & Rockwell, 1994; Chiang, Brooks, & Weir, 2004). At the same time, mean durations of single glances are less dependent of task demands and normally endure for less than 2 seconds (Bruckmayr & Reker, 1994; Zwahlen, Adams, & DeBald, 1988; Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010). Horrey & Wickens (2007) find that although mean glance duration is independent of the complexity of a visual secondary task, more complex tasks are related to a higher proportion of very long off-road

glances. In summary, there is research that reports an influence of the demands of the driving task as well as of the complexity of a visual secondary task on attention while interacting with a visual secondary task in driving. In the project HASTE (e.g. Carsten et al., 2005), participants solved visual and cognitive secondary tasks with different levels of difficulty while driving. Furthermore, in some of the experiments, the complexity of the driving task was also varied. Victor et al. (2005) report that the complexity of both, the visual secondary task and the driving task influences gaze behaviour. The authors report that glances to the secondary task get longer and the proportion of time used for road glances gets smaller with increasing difficulty of a visual secondary task. At the same time, the proportion of time used for road glances is influenced by the road environment: in curves participants use a higher proportion of time for road glances than in straight sections and the duration of secondary task glances is reduced.

The following study was conducted to assess the relative influence of the demands of the driving task and of the secondary task on the distribution of attention in driving with a visual secondary task. Because the demands of the driving task and the complexity of the visual secondary task are varied independently in the experiment, it can also be investigated whether an interaction between the two components exists or whether the driving task and the secondary task influence the distribution of attention independent of each other.

METHODS

Experimental set-up

An experiment was conducted in the static driving simulator at the WIVW (for further information see www.wivw.de, figure 1). During four 15-minute drives on rural roads, the participants solved two different visual secondary tasks. Both tasks were not solved continuously during the drive, but instead they were offered at defined points along the route. The participants were instructed to solve every offered task within a given time frame.



Figure 1: Static driving simulator of WIVW.

Each of the two tasks was solved in two drives. In one of the two drives, the drivers had clear sight; in the other drive it was foggy. In all drives, the rural road consisted of straight and curvy sections. The curvy sections can be divided into low (curvy 1) and high curviness (curvy 2). In total, N=13 secondary tasks were offered, 4 of them on straight sections, 4 on sections with low curviness and 4 on sections with high curviness. During the first secondary task of each drive, the drivers could get familiar with the experimental setup; therefore this task is not included in the analysis.

Both secondary tasks were presented on a display to the right hand side of the driver. For both tasks, inputs were given via a keypad located to the right of the driver. The position of the keypad could be adjusted by the drivers to ensure that the button presses could be conducted easily while driving.

In the first secondary task, the participants were instructed to regulate a simulated controller in a way that the displayed needle was moved onto a given desired value. With one button, the actual value could be raised; with another button it could be lowered. As soon as the desired value was reached, the adjusted value had to be entered by pressing a third button.

The second visual secondary task mimicked a menu system like they are used for instance for in-vehicle information systems. At the beginning of each task, the point in the menu system to be reached was shown to the driver on the so called instruction screen. After reading the instruction, the drivers had to start the task via a button press. The participants could navigate through the menu system until the asked for point had been reached. This was done with the help of four buttons (up, down the list; forward, backward in the menu hierarchy). After reaching the asked for point in the system, the selection had to be confirmed by a last button press.

Both tasks had been tested in a pre-study together with several other visual secondary tasks. The two tasks chosen for the presented experiment were the easiest and the most difficult one of the pre-study. They were chosen in order to enhance the differences between the experimental conditions.

In total, three factors were varied independently in the experiment. Two of them reflect the demands of the driving task, the third of the secondary task.

- Factor sight condition (clear sight vs. foggy): reflects a more long term aspect of the driving situation which influences the demands of the driving task.
- Factor curviness (straight vs. curvy 1 vs. curvy 2): reflects short term situational demands of the driving task.
- Factor type of secondary task (controller vs. menu system): The complexity of the visual secondary task is varied.

Sample and study conduction

In total N=16 drivers participated in the experiment, half of them male. Their age ranged between 25 and 52 years of age ($m=37$, $sd=10$). All participants were sufficiently trained in driving in the driving simulator (Hoffmann & Buld, 2006). The experimental session consisted of four drives in the driving simulator. During two of the drives, the controller task was offered as a secondary task and during the other two, the menu system was performed by the participants. The two drives in which the same secondary task was performed were always presented blocked. The order of the two secondary tasks was balanced across drivers. Each block with one secondary task started with a written description of the secondary task. Afterwards the participants could get familiar with the secondary task during a short drive in which the secondary task was first trained in standstill and then while driving. The order of the two experimental drives with one secondary task (clear sight and fog) was balanced across drivers. After each experimental drive, participants rated the difficulty of the secondary task and of the

driving task. The subjective ratings were given on 15-point Likert-scales on which 1 represents not difficult at all and 15 stands for very difficult.

Data recording

In the driving simulator, all relevant parameters are logged with 120 Hz. Data recording includes parameters describing driving behaviour (e.g. lane position, speed, steering angle, gas pedal position), parameters related to the secondary task (e.g. button pressed, state of the secondary task, errors) and parameters reflecting characteristics of the current driving situation (e.g. curviness, degree fogginess, position along the route).

Gaze behaviour is recorded with the 3-camera system SmartEye-Pro. The positions of the three cameras are chosen in a way that it resembles the likely positioning in a car. Parameters describing head and gaze movement are logged with 60 Hz. The raw eye-tracking data include position and turning angle of the head and gaze direction.

Data analysis

The recorded eye movement raw data is transformed into x-y-coordinates of screen position. These coordinates describe the position where the gaze cuts the projection screen of the simulator. Eye movement data is furthermore filtered with a fixation algorithm. A fixation is assumed if standard deviation of gaze position is below 1° for at least 100 ms (based on Jacob, 1995).

As the main parameter describing eye movement behaviour during secondary tasks, the percentage road centre (PRC) is calculated. In the literature the parameter is used to describe the proportion of gaze that is directed to that part of the visual field in which the further course of the road is situated (Victor, 2005; Victor et al., 2005). To adapt the size and the position of the road centre to situational influences (e.g. differently sized visual fields on different road types (Crundall & Underwood, 1998), median and standard deviation of gaze in a moving 30 second windows are used. The road centre is defined as the area $md [30sec] \pm sd [30sec]$ (see also Metz & Krüger, 2010). Percent road centre is calculated as the proportion of time, in which the gaze is directed into the defined area. Only fixations falling into the road centre are considered as gaze being directed to the road centre, time periods in which no fixations are detected are counted as being outside the road centre. This approach is based on the fact that larger gaze angles (e.g. then looking at a secondary tasks located outside the main axe of sight) are often related to unstable eye tracking. In such periods, sometimes no fixations can be detected because the measured gaze position is too unstable. The parameter PRC reflects the impact of several possible behavioural adaptations: longer fixations directed to the road, a higher number of road-glances as well as shorter off-road glances all lead to a higher PRC for a visual secondary task.

During each secondary task, gaze is coded as being in or out the road centre for every time frame. Based on that, it is calculated how many button presses for the secondary task were actually entered while the driver looked onto the road (and therefore, not onto the display).

RESULTS

Subjective data and performance in the secondary task

Like in the pre-study, the menu system task was rated as more difficult than the controller tasks ($F(1,15)=97.4$, $p<0.001$). There is neither an influence of the sight condition on the rating nor an interaction between the type of the secondary task and the sight condition. The driving task was rated as more complex in the foggy condition ($F(1,15)=15.0$, $p<0.01$). Furthermore, an influence of the type of the secondary task ($F(1,15)=26.3$, $p<0.001$) and an interaction of sight condition and secondary task complexity ($F(1,15)=6.9$, $p<0.05$) can be found. The subjective difficulty of driving differs more between clear and foggy condition in case the simpler secondary task – the controller task – is solved.

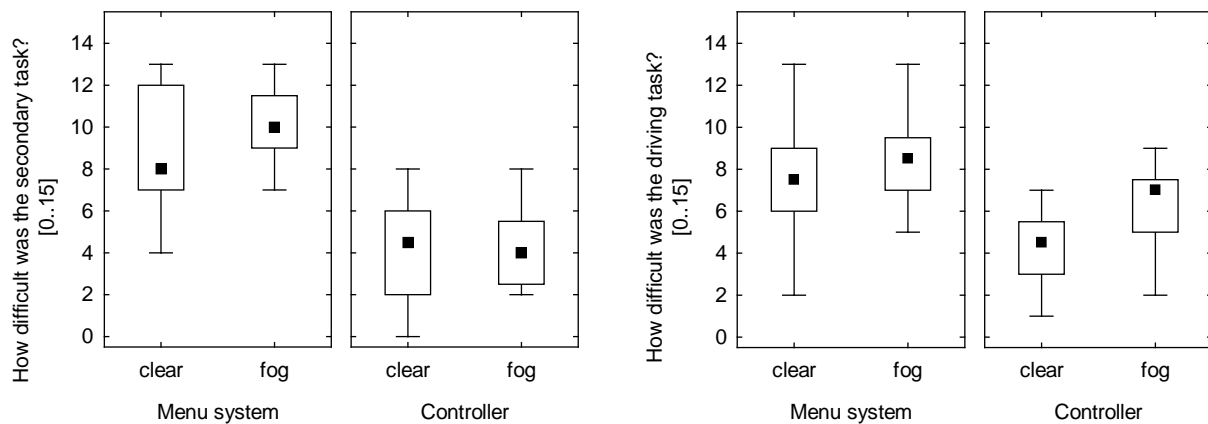


Figure 2: Influence of type of secondary task and of sight condition on subjective rating of difficulty of the secondary task (left) and on subjective rating of difficulty of the driving task (right).

Driving performance and performance in the secondary task

Both secondary tasks were difficult enough that sometimes errors occurred while solving the tasks. An error is counted whenever participants entered a final point in the menu system or the controller task that was wrong or whenever a task could not be solved within the defined time frame. The error rate reflects the subjective rating of difficulty of the secondary tasks: in the menu system more errors are made than in the controller task ($F(1,15) = 7.04$, $p < 0.05$). There is no significant influence of sight condition and no interaction.

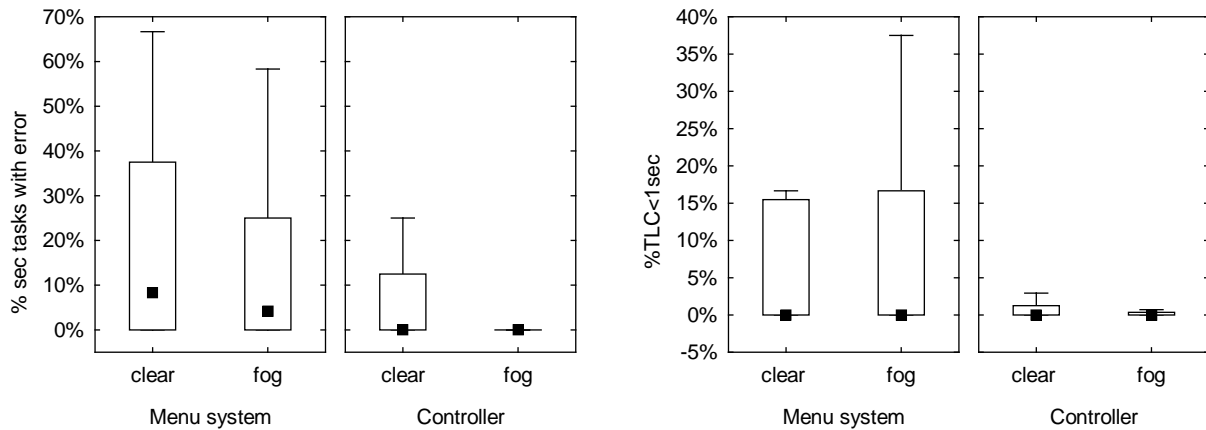


Figure 3: Influence of type of secondary task and of sight condition on error rate in the secondary tasks (left) and on the percentage time with a TLC < 1 second (right).

To evaluate driving performance it is calculated how much time during the secondary tasks the time-to-line-crossing (TLC) is below one second. That parameter is analysed only for straight sections. The more complex secondary task - the menu system - is related to a higher proportion of time with a TLC < 1 second ($F(1,15)=6.2$, $p<0.05$). There is no significant influence of sight condition on driving performance and no interaction.

Gaze behaviour

For the parameters related to gaze behaviour not only the influence of visibility but also of curviness of the current road section can be analysed. For the parameter PRC, a significant difference between the two secondary tasks can be found ($F(1,15)=9.18$, $p<0.01$). During the controller task, more time is spent looking on the road than during the menu system. Furthermore, characteristics of the driving task influence gaze behaviour: In curvy sections, more time is spent looking on the road than in straight sections ($F(2,30)=7.43$, $p<0.01$). The impact of the second factor influencing the difficulty of the driving task - of the sight condition - is less pronounced. There is a tendency that drivers look for a longer time on the road in foggy conditions than in clear sight ($F(1,15)=3.23$, $p=0.092$). There are no significant interactions. The relating effect sizes are 0.81 for the impact of the secondary task, 0.92 for the impact of curviness and 0.39 for the impact of sight condition.

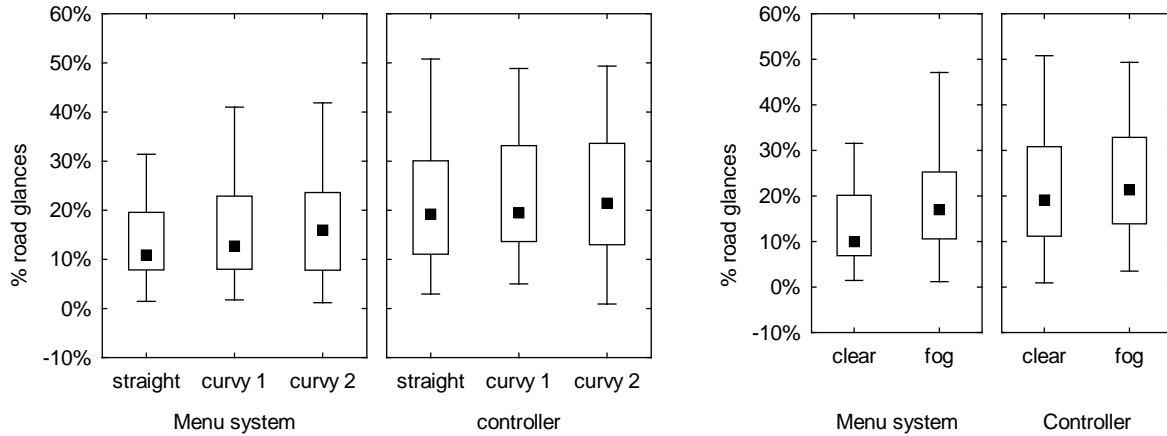


Figure 4: Influence of type of secondary task and of road characteristics on the proportion road glances (left). Influence of type of secondary task and of sight condition on the proportion road glances (right).

Relation between secondary task execution and gaze behaviour

There is a large difference between the two secondary tasks regarding the proportion of button presses performed while looking on the road ($F(1,15)=17.79$, $p<0.001$). With the menu system, 14% of button presses are performed while the driver is looking on the road, in the controller task the proportion is 25%. Furthermore, there is an influence of the road characteristics: on straight sections, less button presses are performed during road glances than in curvy sections ($F(2,30)=5.49$, $p<0.01$). There is no significant influence of the factor visibility ($F(1,15)=2.15$, $p=0.163$) and no interaction. The relating effect sizes are 0.98 for the impact of the secondary task, 0.81 for the impact of curviness and 0.28 for the impact of sight condition.

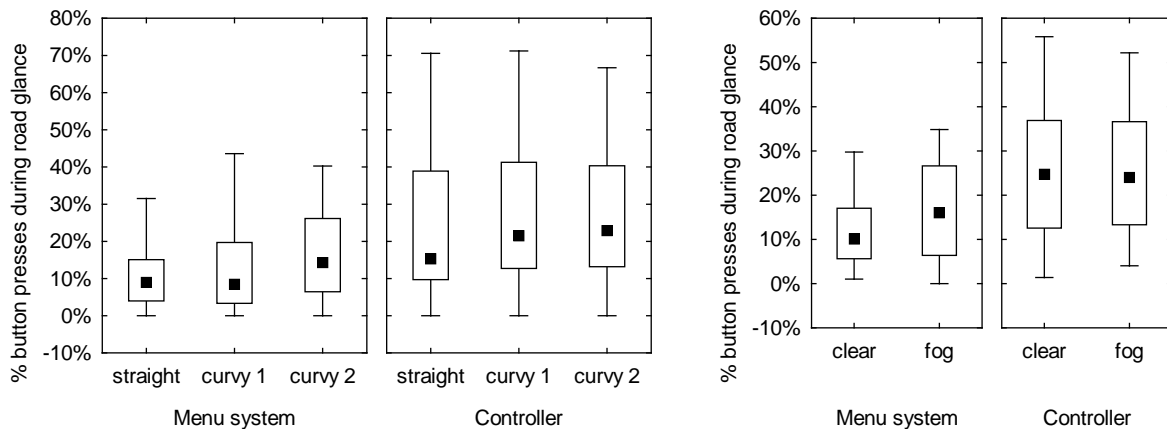


Figure 5: Influence of type of the secondary task and of road characteristics (left) and of type of the secondary task and of sight condition (right) on the proportion button presses performed while looking onto the road.

DISCUSSION

The results on gaze behaviour support the assumption that both, demands of the driving and of the secondary task influence the distribution of attention during distraction. Two visual secondary tasks were studied. One of them, the menu system is not only subjectively rated as more complex; it also has a higher impact on driving performance and more errors occur while solving the secondary task. If it comes to the impact on visual attention, the menu system is related to a higher proportion of time used for glances to the secondary task. This is at least partly due to the fact that with the menu system a smaller proportion of button presses can be made while the driver looks onto the road. One reason for this is that in the menu system, system input often needs visual control, e.g. to know where one currently is in the menu system and where to navigate next. Contrary to that, the controller task requires repeated button presses to move the actual value in the direction of the desired value. This can at least partly be done without visual control.

Besides the demands of the secondary task, the demands of the driving task were varied. Here, short term variation of situational demands, like the curviness of the road, and more long term demands, like the sight condition were differentiated. Results show a pronounced effect of short term demands on the distribution of attention. In curvy sections, a higher proportion of attention is used for road glances and also more button presses are made while the driver looks onto the road. Compared to that, the impact of sight conditions is little. There is only a tendency that more long term demands like fog lead to a higher proportion of attention directed to driving during distraction. The effect sizes show that the impact of the driving situation on the proportion of road glances is higher than the impact of the demands of the secondary task. Furthermore, the curviness of the road does not only impact the proportion of road glances but also the proportion of button presses made while looking onto the road. Independent of the type of the secondary task, drivers perform more button presses while looking onto the road in curvy compared to straight sections. At first glance, this is surprising because how many button presses can be conducted without visual control seems to be a fix characteristic of the secondary task and independent of the driving situation. Therefore, the influence of curviness shows that in undemanding driving situations drivers do not necessarily distribute attention in a way that as little attention as necessary is used for the secondary task. In none of the objective parameters, an interaction between the complexity of the secondary task and the demands of the driving task can be found. This implies that the secondary task and the driving task influence the distribution of attention independently, at least in driving situations with low and medium complexity (like realized in our experiment).

The two secondary tasks chosen for the experiment were developed based on a classification of in-vehicle tasks developed by Daimler. One of the categories relates to handling the on-board system for which the current state of the system is always presented on the central display. The menu-task used in the experiment was developed to simulate interactions with such complex on-board systems that incorporate for instance navigation system, hands-free telephoning and information regarding vehicle state. Another category of the classification includes tasks like changing the radio station or adjusting the volume. The controller task was developed to simulate such in-vehicle tasks that consist of searching for a desired system state along some kind of a

continuum. In a pre-study, the two tasks were studied with two levels of difficulty each. Results showed that the easy menu system task was subjectively and objectively more complex than the difficult controller task. Compared to the differences between the two types of task, variance due to the level of difficulty was little. This is because the two tasks differ in how often and for what visual attention is needed during the task. In the simple task, visual attention is needed to read the desired value and - after adjusting the value - to assess whether the goal has been reached. With the menu task, visual attention is repeatedly needed to get oriented about the current position in the menu system. The aim of the approach chosen in the experiment is to cover the variety of visual secondary tasks in driving better than by using one task with several levels of difficulty (e.g. Carsten et al., 2005, Mattes, 2003).

By using two well defined and highly controlled experimental tasks, it was tried to have good experimental control of the task demands especially because one task was repeatedly performed in changing driving situations. Both task are designed in a way, that they can be repeatedly offered with new goals to be reached (e.g. new desired value, new point in the menu system to be reached), but at the same time task demands remain comparable. Another approach that can be found in the literature is to use a variety of real-life secondary tasks (e.g. Angell et al., 2006). The advantage of that approach is that the variety of secondary task demands can be covered realistically; at the same time, the differences between the tasks are under less experimental control and it is more difficult to use the same task repeatedly with comparable difficulty at defined points during one experimental drive.

The results on the number of button presses performed without looking onto the secondary tasks show that one important aspect of secondary tasks difficulty is how often feedback is needed to solve the task and how that feedback is provided to the drivers. The secondary task which could be solved with only little feedback about the current state of the task is subjectively and objectively easier than the task requiring visual feedback more often. At the same time, it seems likely that tasks providing auditory feedback – like adjusting volume or the radio station – are less distracting than tasks providing only visual feedback – like searching for something in the on-board system or changing the position of the mirror.

The results of the presented experiment support the assumption that during visual distraction drivers take situational demands of the driving task into account. They do not interact with visually distracting tasks without considering the affordances of the driving task. Instead, situational demands of driving are reflected in how much visual attention is used for monitoring the driving task during distraction. By this, drivers presumably try to compensate for negative effects of distraction in driving in accordance with the current demands of the driving situation. If and under which conditions this adaptation of attention to the demands of driving is sufficient to prevent driving errors cannot be inferred from the reported experiment. Instead, it is necessary to study the impact of demands of driving and of the secondary task in more complex and probably also in critical driving situations. It might be that the reported independence of demands of driving and of the visual secondary task on the distribution of attention does cease to exist as soon as the combination of both tasks reaches the limits of available attentional resources. Therefore, more research is needed to study the influence (and possible interaction) of the demands of driving and of secondary tasks. To receive valid results

regarding the impact of visual secondary tasks on driving safety, future research should also try to incorporate the second possibility of adapting secondary task interaction to driving demands: Since drivers report that they avoid distraction in highly demanding situations, they should not be forced to interact with distracting tasks in highly demanding driving situations. Instead, they should be free to choose in which situations they think distraction is appropriate. Otherwise, it might be the case that a critical impact of distraction on driving is produced by the implemented experimental setup.

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