COGNITIVE DISTRACTION AND DRIVERS' ADAPTATION IN DIFFERENT DRIVING MANOEUVRES IN REAL TRAFFIC

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ABSTRACT

There are numerous studies demonstrating the negative effects of cognitive tasks on driving performance. But there are also studies that indicate that drivers might be able to adapt their driving behaviour to these negative effects. Recently, it was found in a driving simulator study that drivers adapted their safety margins when performing steady-state manoeuvres, but did not so when performing tactical control manoeuvres. The aim of our study was to examine this phenomenon under real driving conditions for middle-aged and elderly drivers. The results indicate that elderly drivers compensate more for cognitive distraction during tactical control manoeuvres. This might be due to their greater impairment caused by cognitive distraction.

KEYWORDS

Cognitive distraction; compensation behaviour, steady-state manoeuvres; tactical manoeuvres; real driving study;

INTRODUCTION

The number of in-vehicle information systems available in modern cars increases dramatically in recent years [1]. For example, the number of cars that were sold in the US with navigation systems fitted in shows a six-fold increase from 2000 to 2002. Furthermore the number of functions that these systems provide and that can be accessed while driving grows even more. Whereas in 1990 70% of the in-car entertainment systems installed in US vehicles had less than 12 buttons, in 2001 the proportion of in-car entertainment systems that had less than 12 buttons dropped to 35% [2]. Additionally the use of so-called nomadic devices – communication, information, and entertainment devices, such as a PDA, a mobile phone or an MP3 player – while driving also increases at least with the same rate. For example, two thirds of Finish drivers [3] and 85% of American drivers [4] use their mobile phones while driving according to recent studies.

Whereas these systems are mainly intended to increase the driver's comfort and safety interacting with these systems while driving can also distract the driver from the primary driving task resulting in an actual reduction of driver's safety. Distraction and driver inattention are one of the major factors associated with motor vehicle crashes. There are estimations that 25-50% of such crashes involve some form of distraction or inattention ([5] – [8]). The results of most recent studies indicate that up to 78% of crashes and 65% of near-crashes are linked to some kind of driver inattention [9]. Whereas the sources of driver distraction are manifold in-vehicle information systems and especially nomadic devices play also an important role as sources of driver distraction [10]. Interaction with such systems does not only cause visual distraction as the driver in many cases has to turn the gaze from the street to the system when interacting with it. Interacting with the systems can also cause cognitive distraction as the driver has to handle multiple tasks simultaneously in such a situation, namely driving and system operation. Additionally, interacting with the system may involve navigating through menus, deciding which method to use to achieve the intended interaction goal most efficiently, or memorizing information that was presented in one display and needs to be used for input on the following display. All these tasks or subtasks of interaction sequences with in-vehicle devices are associated with cognitive demands and therefore cause cognitive distraction when performed while driving.

There are numerous studies demonstrating the negative effects of cognitive distraction on driving performance (e.g., [11] – [23]). These studies generally find an increase in response latencies of drivers performing cognitively loading tasks ([17], [19], [20]), a decrement in the breadth of visual scanning [21], impaired anticipation of braking requirements ([15], [22]) or the impaired comprehension of perceived situation elements [23].

Whereas these studies clearly demonstrate that cognitive distraction impairs driving performance, there are also studies indicating that drivers are able to adapt their driving behaviour to the impairments resulting from cognitive distraction to allow them to maintain their accepted target level of driving safety. Drivers seem to be able to estimate the workload associated with different driving manoeuvres and traffic situations rather validly. Schießl [24] showed in a driving simulator study that drivers are able to estimate the short-term changes in workload induced by different driving manoeuvres online. The drivers' subjective ratings of workload collected while the drivers entered a highway correlate with physiological measures of workload and show a clear differentiation of workload associated with the different phases of the entering manoeuvre. The drivers estimated the phase of the actual lane change as the most demanding one and this phase was also associated with highest mean heart rate. Rauch and colleagues [25] examined whether drivers consider the current demands of the driving situation in their decision to start a secondary task or not while driving. In their driving simulator study drivers had to manage several driving situations associated with different levels of situational demands. At certain points during the driving simulation they were offered the choice to perform a secondary task. This could be either directly before a critical situation or during a non-critical situation. The results show that the drivers were aware of the higher demands of the critical situation compared to the non-critical situation. They rejected the secondary task more often in critical than in non-critical situations.

This is in accordance with results of studies on the use of cell phones in everyday driving. Interview [27] and observation studies [28] indicate that drivers use specific compensation strategies when using their cell phone while driving. Some drivers do not use their cell phone at all when driving. Some use it only when waiting at a red traffic light. While calling, drivers tend to drive more slowly, avoid lane changes, or choose sections with low traffic density. In demanding driving situation drivers indicate that they would interrupt the conversation on phone.

This adaptation of driving behaviour to increased workload caused by secondary tasks can also be found in more controlled experimental studies. Brookhuis and colleagues [29] found in a driving study in real traffic that participants increased the distance to the lead car when engaged in a telephone conversation task. Strayer and colleagues [30] found a similar result in a driving simulator study and Ranney and colleagues [31] in a closed test-track study.

These studies generally focus on the driving behaviour during steady-state manoeuvres, such as car following (e.g., [30], [31]. But recently, Horrey and Simons [32] examined the impact of cognitive distraction on safety margins in a driving simulator study when drivers performed both steady-state manoeuvres and tactical control manoeuvres, such as overtaking other vehicles. Whereas such steady-state manoeuvres involve many important aspects of the control level of the driving task [33], such as maintaining a safe distance to the lead car, keeping the lateral position and controlling speed, they involve to a much lesser extent aspects of the manoeuvre and the navigation level of the driving task. But this is the case for tactical manoeuvres. This is especially important as these higher levels of the driving task also involve higher cognitive processes, such as assessing situations, planning manoeuvres, changing goals, or selecting appropriate actions. As these processes are in most cases not automatic, but require the availability of cognitive resources, such as attention and working memory, they are especially vulnerable to cognitive distraction. If drivers are aware of their cognitive distraction and the impairments they suffer they should also show compensation behaviour when performing tactical control manoeuvres. Whereas the observational data point in this direction, when drivers tend to perform less lane change manoeuvres while using their cell phone ([27], [28]), Horrey and Simons' [32] results show a different picture. They found that drivers adapted their safety margins, in this case time headway, when performing a secondary task while driving steady-state manoeuvres, but did not so when performing a secondary task simultaneously with tactical control manoeuvres. On the contrary, the drivers showed reduced safety margins to adjacent cars during tactical control manoeuvres, such as overtaking, leading the authors to the conclusion that cognitive distraction leads to even riskier driving.

Because of the discrepancy between the results of observational and interview studies on driving behaviour under real traffic conditions and the results of the driving simulator experiment conducted by Horrey and Simons [32] we decided to examine the effect of cognitive distraction on the execution of steady-state and tactical driving manoeuvres in real traffic. Furthermore, Horrey and Simons had only rather young drivers in their study. The participants' mean age was 20.8 years in the first experiment and 18.9 years in the second experiment. But there are many studies reporting age differences with regard to the effects of cognitive distraction on driving behaviour. Older drivers on the one hand have more difficulties in performing a secondary task while driving (e.g., [34]) but on the other hand tend to compensate better for these difficulties when performing a secondary task while driving (e.g.. [35]) than younger drivers. As it consequently seems that older drivers possess compensation strategies that are different from younger drivers we included two age groups in our driving study to test for age differences in possible compensation strategies for cognitive distraction.

To summarize, the aim of our study was to examine the applied compensation strategies for cognitive distraction under real driving conditions where the need for the adaptation of driving behaviour due to impairments by cognitively distracting tasks is much higher than in a driving simulator study. Additionally, we examined the effects of cognitive distraction and the drivers' adaptation for two groups of drivers: middle-aged drivers between 30 and 45 years and elderly drivers older than 65 years. Especially the elderly drivers where expected to show compensation for the cognitive distraction also in tactical control.

METHOD

To examine the driver behaviour a motorway test route of about 220 km length (Figure 1) was chosen, where steady-state as well as tactical control manoeuvres could be performed by the drivers. The test route consisted of a two-lane motorway section which constituted the main part. For the variation in traffic density, a three-lane motorway section at the end of the test drive was added.

Figure 1 - Test route

The different driving scenarios that were recorded during the experiment were:

Free driving (FD): driving without a lead car. The own car is driving on a street and follows its course, there is no lead car (or there is a lead car but too far away to influence driver's behaviour, e.g. TTC to lead car >= 5 sec).

Approaching a Slower Vehicle (ASV): The own car is approaching a slower lead car driving on the same lane. The car should reduce its speed to adjust to the lead car's speed.

Approaching a Traffic Light (ATL): The own car is approaching a traffic light that turns yellow or red or is already red. That is, it signals the driver to stop. If the traffic light is green the manoeuvre is more like driving with or without lead car.
Car Following (CF): The own car is following a lead car; own car and lead car have about the same speed.
Overtaking (O): The own car is overtaking one or more other vehicles driving with less speed than the own car. Thereby the own car performs a lane change to the left, passing the slower vehicle(s) (not staying for more than 10 s in the left lane, otherwise, it would be considered as a lane change left) and then performing a lane change to the right again.
Change Lane Left / Right (CLL/CLR): The own car changes on a multi-lane street to the left or to the right adjacent lane. This lane change can be due to a slower vehicle on the starting lane that will be passed during the manoeuvre (i. e. being a lane change to the left), but only if this manoeuvre is not completed with a lane change to the right within the next 10 seconds. Otherwise, in this case it would be an overtaking manoeuvre.

Participants

To consider different compensation strategies two driver groups were selected. A middle aged group with drivers from 30-45 years and an older drivers group starting at 65 years. Each group consisted of 11 drivers whereas 36% of them were female drivers. Additionally, driving experience was controlled. In order to achieve a considerable experience and an appropriate level of homogeneity, a minimum driving experience of 6000 km/year was requested.

Procedure

The experiment was conducted with DLR's instrumented vehicle ViewCar with which driving performance as well as relevant aspects of the driving situation, such as time headway to the lead car, could be recorded. Additionally, the performance in the cognitively loading task was recorded. The aim was to record longitudinal control behaviour during driving with and without a lead car, with different speed limits, during lane changes to the left and right, and during overtaking manoeuvres.

After the administration of initial questionnaires, participants completed a driving phase dedicated to make them familiar with the instrumented vehicle. After this the experimental phase started and during each drive there were phases where participants had to drive only (single-task) and phases where they had to perform a cognitively loading secondary task concurrently (dual-task). Several single-task and dual-task phases were alternated along the drive. As a whole, each test lasted around 3 – 4 hours, considering the driving session itself and the administration of questionnaires at the beginning and at the end of the trial.

Secondary Task

As cognitively loading secondary task, participants had to perform a mental arithmetic task. At the start of each dual-task phase participants were presented with a three-digit number (e.g. 539) from which they had to count backwards by three. This was triggered by the experimenter and paced by an acoustic signal that was presented every 2 sec. During each cognitive task 30 such signals were presented. Their responses were recorded, so that participants' performance in the secondary tasks could be assessed. For the data analysis each of the 30 answers given by the participants during a secondary task was assigned into one of the following five categories:

- Correct answer (1),
- Miscount (2),
- Miscount with correction (3),
- Drop out (i.e., the participant was lost in the secondary task and the experimenter had to give a new number as starting point) (4),
- Miss (i.e., the answer was not given before the next acoustic signal was presented) (5).

The time interval between dual-task phased varied randomly between 8 and 12 min with a mean of 10 min. The experimenter took care that the secondary task was not started or finished during the performance of a tactical control manoeuvre, such as overtaking.

RESULTS

Secondary task performance

Preliminary analyses of the performance in the secondary task show that the error patterns for middle-aged and elderly drivers are different when performing the different manoeuvres. Elderly drivers show more errors in the counting task during overtaking manoeuvres than the middle-aged drivers. Overall number and percentage of error frequencies in the different categories for the two age groups are displayed in Table 1. It is noticeable that the categories are equally distributed, so there are no differences between both groups.

Table 1 - error categories for younger and older drivers (number and percentage)

	younger drivers	older drivers
error		
correct answer	3840 (85.4%)	2951 (81.3%)
miscount	74 (1.6%)	67 (1.8%)
scount with correcti	39 (0.9%)	37 (1.0%)
drop out	69 (1.5%)	81 (2.2%)
miss	476 (10.6%)	494 (13.6%)

In a next step we analysed the number of driven manoeuvres within each error category (category 1 as correct answer excluded) and performed an X^2-Test to compare the frequencies. Significant differences were found for the error categories “miscount” ($X^2_{18.32}$, df $_3$, p= 0.00) and “miss” ($X^2_{33.16}$, df $_3$, p= 0.00). As shown in Figure 2, the percentage of overtaking manoeuvres within the error category “miscount” is significantly higher for the older drivers, whereas younger drivers show a higher percentage of car following.

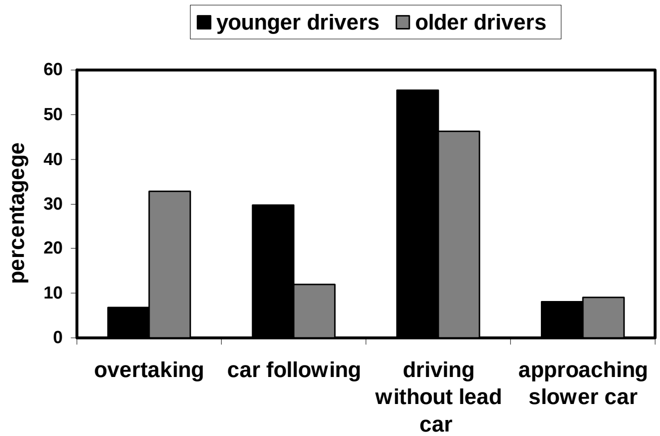

Figure 2 - percentage of driving manoeuvres for error category "miscount"

A similar pattern can be demonstrated for the category "miss" (Figure 3). The percentage of overtaking manoeuvres within the category "miss" is higher for the older drivers group than for the younger drivers.

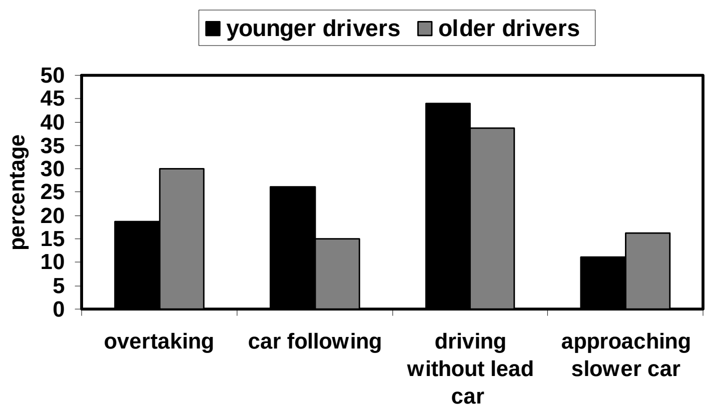

Figure 3 - percentage of error driving manoeuvres for error category "miss"

Driving performance

With regard to driving performance we first examined how often manoeuvres were performed correctly depending on task condition (single versus dual task) and age group. The analysis will be restricted to the manoeuvres Overtaking, Car following, Driving without lead car (Driv. Wo LC) and Approaching a lead car (Approaching LC) as the other manoeuvres occurred too rarely to conduct a reliable analysis. Figure 4 shows the rate of manoeuvres performed correctly. Only the relative frequency of correct overtaking manoeuvres shows a small difference between manoeuvres with and without secondary task performance. And this is true only for the middle-aged group. Middle-aged drivers make slightly more errors during overtaking when they simultaneously perform the secondary task than when not. The older drivers show no effect of secondary task performance in terms of frequency of correctly executed manoeuvres.

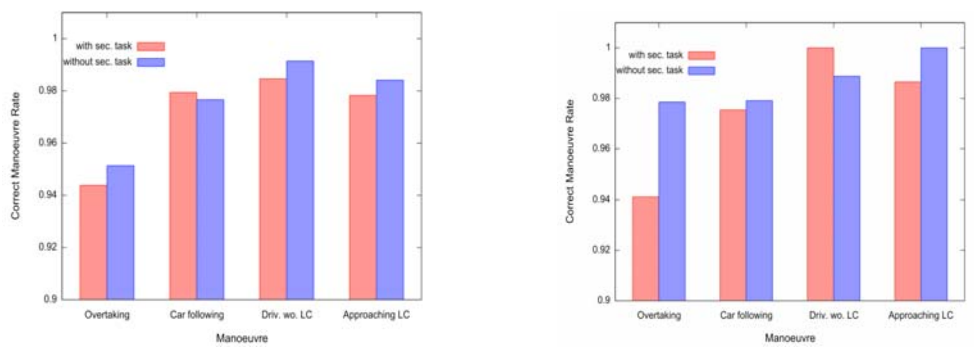

Figure 4 - Rate of correctly performed manoeuvres fort he older (left) and middle-aged (right) drivers

In Figure 5 the average distance between the driver and the lead car at the beginning of an overtaking manoeuvre is presented. The results indicate that older drivers tend to start the overtaking manoeuvre with a slightly increased distance to the lead car when performing a secondary task, middle-aged drivers show no difference between single and dual task condition.

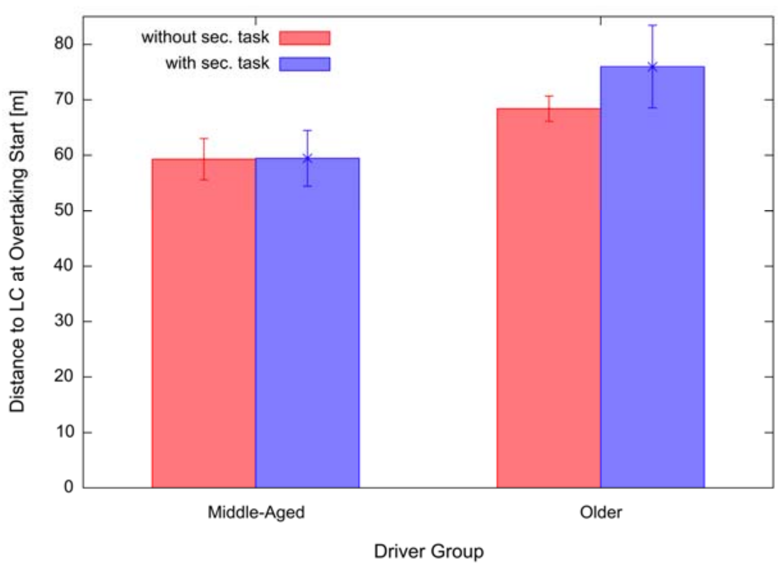

Figure 5 – Distance between driver and lead car at the beginning of the overtaking manoeuvre

Figure 6 depicts the average speed of the driver when starting to overtake. As can be seen both driver groups drive more slowly at the beginning of the overtaking manoeuvre when performing a secondary task than when not. Taking into account that the older drivers also increased distance and the middle-aged not indicates that older driver increased their safety margin more than the middle-aged drivers.

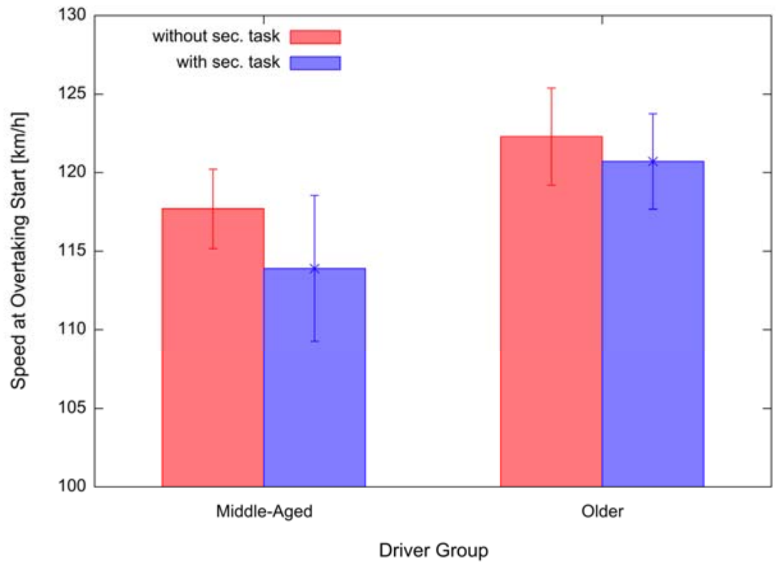

Figure 6 – Average speed of the participants when overtaking manoeuvre started

The driving performance during car following was also examined more deeply. Figure 7 presents the average minimum time headway (THW) that occurred during the car following manoeuvres. The older drivers show a slightly increased minimum THW compared to the middle-aged drivers. But both the middle-aged and the older drivers show no effect of secondary task performance on minimum THW. There is no indication of compensation behaviour during car following manoeuvres.

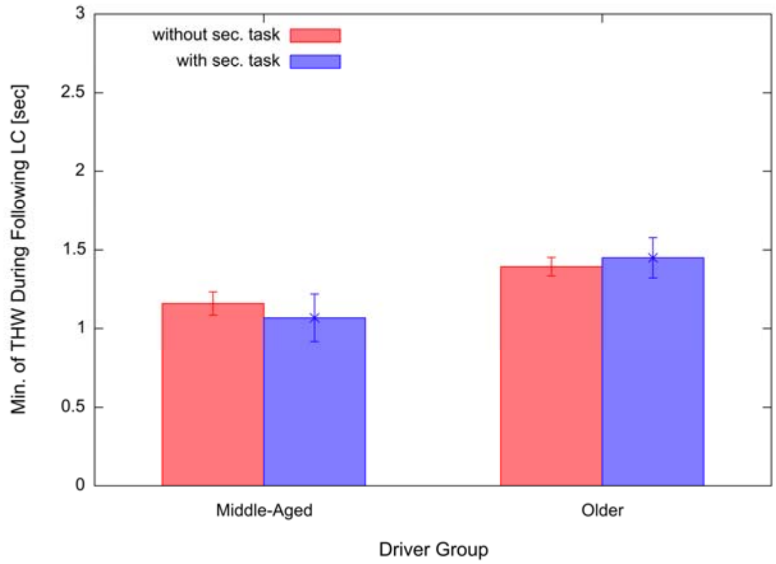

Figure 7 – Average minimum time headway (THW) between participant and lead car during car following manoeuvres

DISCUSSION

The study aimed at examining compensation behaviour for cognitive distraction when executing steady-state and tactical manoeuvres under real driving conditions for middle-aged and older drivers. Previous studies had shown that drivers compensate for cognitive distraction when performing steady-state manoeuvres but not when performing tactical manoeuvres [32] but the age of the drivers was not considered.

The results of our study lend some preliminary support to the assumption that there might be different compensation strategies for cognitive distraction between middle-aged and older drivers when performing tactical manoeuvres but not when performing steady-state manoeuvres. Older drivers increased the distance and decreased their speed at the beginning of an overtaking manoeuvre when they simultaneously had to perform a cognitively demanding task compared to driving without secondary task. Middle-aged drivers did show less compensation. During car following both driver groups showed no compensation when performing the cognitively demanding task. This clearly contradicts the results of Horrey and Simons [32].

The different compensation strategies between middle-aged and older drivers might be the consequence of different effects of the secondary task on both driver groups. In accordance with previous studies (e.g., [34]) older drivers showed more difficulties in performing a secondary task while driving. For older drivers such a dual task situation is more demanding than for younger drivers therefore the need to compensate is clearly higher. Why this did only show up when executing tactical and not when executing steady-state manoeuvres is the focus of a more deep examination of the data which is currently carried out. Here we will consider the possible additional effects of situational variables such as traffic density on the performance of the driving manoeuvres that might have moderated the effect of cognitive distraction on driving behaviour.

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