EFFECTS OF VISUAL SEARCH TASK COMPLEXITY ON LANE CHANGE TASK PERFORMANCE

Ellen S. Wilschut (IfADo, Germany),
Gerhard Rinkenauer (IfADo, Germany),
Karel A. Brookhuis (Groningen University, The Netherlands),
Michael Falkenstein (IfADo, Germany)

wilschut@gmx.de

ABSTRACT: Driver assistance systems are increasingly implemented in motor vehicles. However, it is unclear whether the secondary tasks introduced by these systems affect driving performance and whether they cause safety risks to the driver and road traffic. In this study the effect of secondary task complexity on driving performance is manipulated using different complexity manipulations of a visual search task. The lane-change task [19] was used as the primary task to simulate driving. Results showed that participants (n=12) were unable to maintain their baseline driving performance when the secondary task had to be performed. Moreover, they showed further dual task decrements with increasing visual search complexity. The results show adverse effects on simulated driving depending on the complexity of an additional task.

1 Introduction

The most frequently implemented in-vehicle information systems (IVIS) nowadays are the In-Vehicle Routing and Navigation Systems (IRANS) that provide drivers information about the route from one destination to another [4]. Research has shown that under some circumstances dual task decrement can affect driving performance [5, 6, 14, 15, 23]. However, people are engaged in concurrent tasks on a daily basis, like drinking coffee while watching the news. Most of these tasks are highly practised and are therefore highly automated [22]. People are fairly good at performing multiple tasks at the same time provided at least one of them is (highly) automated, and in case the execution of a task threatens to fail, people have a large range of coping mechanisms available. There are at least three ways in which drivers can adapt their behaviour to cope with higher task demand [3, 13]. These are: investment of more effort, changing working strategy and neglecting subsidiary information. In a study of Dingus et al. [9] IRANS with the highest visual demand were associated with the lowest driving speed. Thus drivers adapted their working strategies and made the driving task less demanding by lowering their speed [see also 12]. It is expected that driver will adjust their strategies to deal with this additional task demand and reach what can be described as homeostasis or an optimum level of accepted risk or task difficulty [11, 12, 27]. For instance, Pohlmann and Traenkle [21] also found speed reductions and a deterioration in lateral control with high visual demand of IRANS. They found this effect particularly near intersections. Drivers reduce speed to allow time to drive safely and were highly motivated to check the IRAN system, even in difficult traffic situations. Unfortunately, it is especially near intersections which are complex traffic situations that the need for route information is high [8]. So this could be a situation where task demands are higher than normal and possibly cause dual task decrement. As long as the driving task is self-paced and compensating strategies can be executed the interference of secondary tasks will be limited. However, driving can also be paced by the environment. For instance driving 30 km/h on the highway can be done theoretically, but is certainly more hazardous than missing the highway exit. In that case compensating by considerably reducing speed would hardly be possible. So there are situations in which compensating strategies are not sufficient or can not be executed, and when this is the case and task demand is high, driving performance is likely to suffer.

1.1 Visual search

Using a digital map requires searching and detecting relevant information. If the system is well-designed this search for relevant information is efficient, requiring the driver to take the eyes off the road for a minimum amount of time. Complex colouring, multiple signs and long text messages in displays make the search for information demanding and inefficient, and require multiple glances. Factors that influence the search time of a display have been widely studied using all kinds of visual search paradigms. Visual search is easier when the target can be defined by one feature such as colour, e.g. the target colour (blue) is different from its distractor (red). Within the Feature Integration Theory [25] this type of feature search is called *pop-out*. When a target is defined by a *conjunction* of two or more features, for instance the target is a blue letter ’A’ between distractors consisting of blue ‘T’s and red ‘A’s, search for a target is slower. The time needed to search for a conjunction target becomes slower as a function of the *set size* (the number of elements in a search display) while search for a pop-out target will be relatively independent of set size. Theories on attention try to explain this difference in reaction times [18] between searching for conjunction versus pop-out targets. The fundamental nature of this attentive selection process is still under debate to date [10, 17, 25], but clear is that there is not such a clear dichotomy in visual search as desribed by Treisman, therefore Wolfe [28] suggested to use the term “efficiency” to describe the continuum of search complexity. The efficiency of visual search depends for instance on the number of distractors and on the number of features in the display (e.g. form and colour). A typical finding is that more distractors and more equality between distractors and targets makes the visual search less efficient, slower and less accurate [24, 29]. Interesting research has been conducted in the HASTE project [20] in which a visual search task is used as a surrogate IVIS. The visual search task was performed both in isolation and concurrently with a laboratory driving task, in a driving simulator and while actually driving on the road. The visual surrogate IVIS task of HASTE consisted of a choice-reaction task with three difficulty levels as shown in figure 1. Each display contained a mixture of pop-out and conjunction displays i.e. of the different classes of search requirements. Results showed that the difficulty of the visual task had a pronounced effect on steering (a higher steering reversal rate) and lateral behaviour (higher standard deviation of the lateral position). Also the increased secondary taks load let to speed reduction and increase in headway.

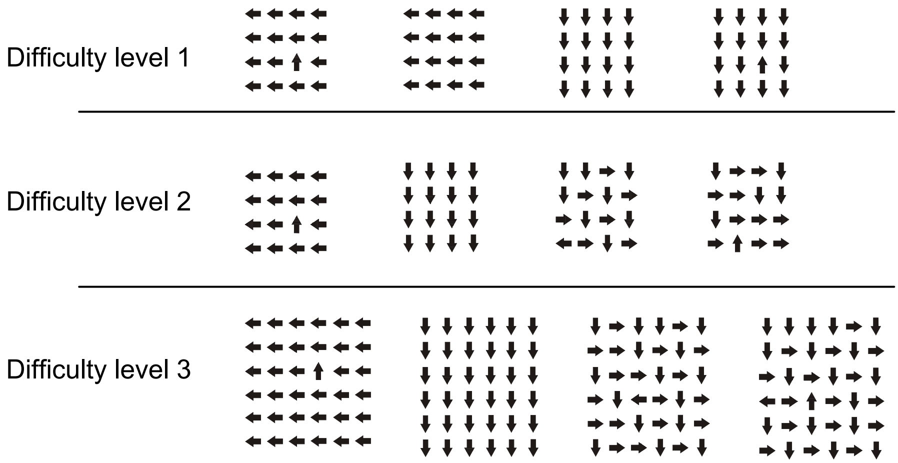

Fig.1. Example displays of the surrogate IVIS displays. Within each difficulty level there are in fact different types of displays. For instance in difficulty level 2 one fourth of the displays are pop-out displays (the upward pointing target arrow ‘pops out’ in left display). And the other part of displays require conjunction search.

1.2 Aim of the study

The aim of the present study is to extend the previous research by focusing on the effect of search difficulty (pop-out versus conjunction) and the effect of set size. Another factor that differentiates the present study from the HASTE experiments is that driving speed was fixed at 60 km/hour. Thus participants were unable to compensate for the task demand by decreasing their speed. In the present study the effect of secondary, visual search complexity on driving performance is evaluated, using a visual search task as a surrogate IVIS and the lane-change task as the primary task to simulate driving [19]. Both tasks were performed separately to acquire the baseline values of each participant, and are then compared to the performance of the two tasks in a dual task situation. In this dual task situation the lane-change task was defined as the primary task which is instructed to be given the highest priority. It was expected that in the dual task situation the performance of the visual search task would decrease and the secondary task may have a possible negative effect on the simulated driving task if the participants are unable to fully prioritise the LCT-task or compensate for the dual task demand. We expect this effect to be larger with increasing set size and with conjunction search displays.

2 Method

2.1 Participants

Twelve female participants aged between 20 and 22 years (M=20.3 (±0.6)) participated in a experimental session in exchange for a partial course credit.[1] All participants had their driver's licence for at least 2 years and had normal or corrected to normal vision. The experimental procedure consisted of three different parts. The first part was a simulated driving task called the lane change task [19]. The second part was a visual search task. The sequence of these two parts was counterbalanced across participants. The final part of the experiment combined the simulated driving and the visual search task. Each part started with a training block. In total participants received about half an hour of training. The training of the visual search task continued until the participants reached a minimum of 80% correct trials. Each part was followed by a short break.

2.2 Primary simulated driving task

The simulated track consisted of a straight three-lane road. With the gas pedal pressed maximally the participant drove a constant 60 km/h. This resulted in a total driving time per track of about 3 minutes. There were 18 signs along each track indicating the lane the participant had to change to as soon as the sign was identified. Signs were present with a mean distance of 150 m (min. 140 and max. 188 metres, exponentially distributed). Each of the 6 possible lane changes occurred three times during one track. The performance on six different tracks was measured of which the first two were considered training. Data were continually sampled with a scan rate of 130 Hz, namely the lateral and longitudinal position, speed (as a control) and steering angle. As a measure of driving performance the deviation between a normative model and the participants' actual course on the track was calculated [19].

2.3 Secondary visual search task

In the visual search task each experimental trial began with the presentation of a fixation cross, which remained on screen for 1000 ms. The fixation cross was followed by the presentation of a visual search display for 3000 ms. The display types consisted of a complexity manipulation pop-out/conjunction and a set size manipulation (4 versus 9 items). The four types of display were blocked and randomly presented to the participants. Participants were presented with 8 blocks, each consisting of 40 trials. The target stimulus was either an upward green arrow or a right-pointing red arrow, only one target was present per trial with a 50% change. The target appeared on a random location. The non-targets were all other combinations of green or red arrows with orientation to the left, to

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[1] Since this experiment was part of an university course, therefore participants were not divided equally across gender. Adam [1]showed that female spatial choice-RTs were about 34 ms slower than those of male participants and different strategies were adopted per gender group, effects like this should be considered when determing the external validity of the study.

the right, up or down. The participant had to indicate by a button press whether the target was present or not. They were instructed to react as quickly and accurately as possible. In the pop-out displays the target was distinguishable from the non-target either by colour or orientation. Thus there were two possible situations: distractor arrows all pointed in the vertical direction when the target was a red right-pointing arrow or when the target was a green upward arrow, all distractors were red. In conjunction displays the non-targets pointed in all directions and the amount of red and green arrows was equal.

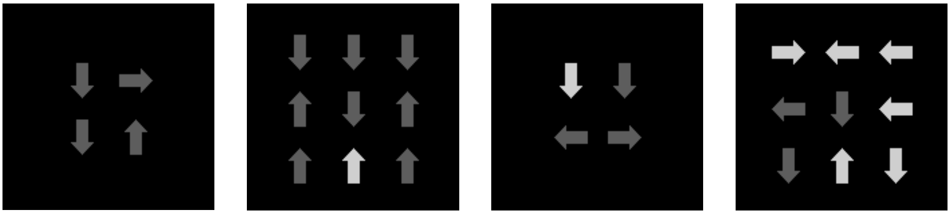

Fig.2. Four example displays with the two different target arrows (displays are described from left to right): The two left displays are the pop-out search displays; participants can discriminate target arrows from distractor arrows by looking at direction or colour. In display 1: a red arrow (= grey) pointing to the right or in display 2: a green (= white) upward pointing arrow. The displays on the right side are the conjunction search displays, where both features colour and direction have to be determined to find the target. The same targets are presented in display 3: a red arrow pointing to the right and display 4: a green upward pointing arrow.

2.4 Dual task

In the dual task the instructions and conditions for driving as well as for the visual search task were kept equal and the participant was instructed to give first priority to the driving task. The constant, required driving speed of 60 km/h made it impossible to compensate for secondary task difficulty by reducing speed. In each of the eight blocks one of the four visual search conditions was presented. Each condition was thus presented twice and the order was random.

2.5 Equipment and analysis

For tracking a simple Logitech gaming steering wheel was used with gas and brake pedals. The visual search task was displayed on a small LCD screen at a distance of 1.45 m with a visual angle of 18°. This LCD screen was positioned in front of the main screen (distance 1.96 cm, visual angle 38° x 29°) without blocking the sight on the road. For stimulus presentation E-prime was used (Psychology Software Tools, Inc., Pittsburgh, USA) the small set size was visible within 1°, the large set size within 1.6°. Two of the original response buttons behind the steering wheel were adapted to make accurate RT acquisition possible using the printer port. Data were subjected to ANOVA repeated measurement analyses of SPSS 13.0, except for training blocks. In case of sphericity violation the Greenhouse-Geiser modification was used. Within-subjects factors were complexity (pop-out/conjunction), set size (4/9 items) and single versus dual task performance. For the behavioural results of the visual search task target and non-target reactions are combined in the analysis.

3 Results

3.1 Visual Search

The analysis of the RT showed that participants took on average 86 ms longer to react in the dual task situation ($F(1,11)=4.3$, $p=.063$; see table 1). RTs were about 1000 ms slower for conjunction displays where participants had to search for a target looking at its two features colour and rotation ($F(1,11)=425.8$, $p<.001$; see figure 3a). Participants were reacting on average 260 ms slower for the large (nine elements) displays then for the small (four elements) displays ($F(1,11)=194.1$, $p<.001$). Also the expected interaction between complexity and set size of the visual search task reached significance ($F(1,11)=110.0$, $p<.001$) showing a larger increase of RTs with set size when the displays were conjunction displays.

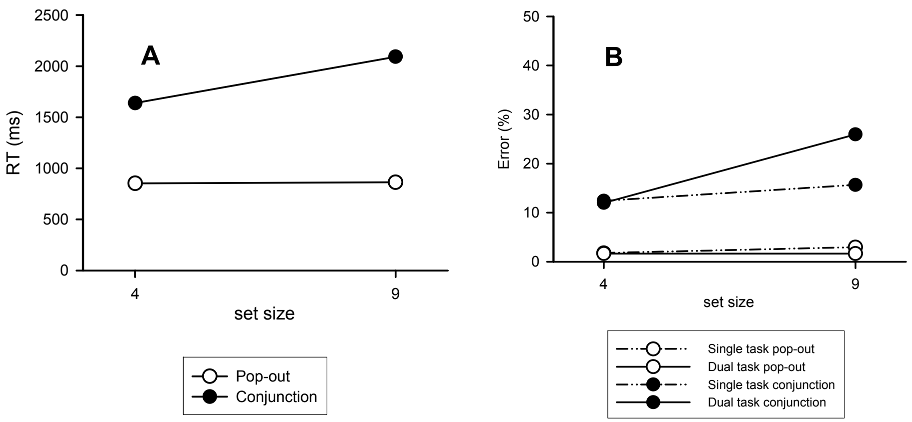

Fig.3. A) Reaction times of the visual search task in the dual task condition (averaged over target and non-target displays) for the conditions set size and efficiency. B) Errors in percentage of the visual search task in single and dual task condition (averaged over number of false alarms and misses). The increase of the percentage of errors with dual task can be attributed to the increase in the number of misses.

Participants hardly made any errors with pop-out displays, i.e. 0.2% compared to 16.5% with conjunction displays ($F(1,11)=96.6$, $p<.001$). Also with larger set size the amount of errors increased ($F(1,11)=19.2$, $p<.001$). And the interaction between set size and the complexity of search was significant showing the same direction as RTs, i.e. the amount of errors increased more with set size when the displays were conjunction ($F(1,11)=13.1$, $p<.004$). Participants made significantly more errors in the dual task condition; 8.5% in single task performance versus 10.6% when performing the visual search task together with the lane change task (F(1,11)=6.2, p<.030). Within the dual task the number of errors increased for display complexity (F(1,11)=12.2, p<.005), set size (F(1,11)=16.0, p<.002) and also the interaction between complexity and set size was significant (F(1,11)=24.8, p<.001). This interaction showed that when the visual task is performed as a dual task the number of errors increases and the errors increase more drastically for conjunction displays with a large set size. When looking at the type of error (false alarms and misses see table 1) in the dual task situation, there is no significant difference in the false alarms, so the effect can be attributed to an increase in the number of misses in the dual task condition.

3.2 Primary task

The mean deviation from the ideal lane keeping (the normative model) showed an effect of dual task (F(4,44)=11.9, p<.001). It showed that even in the most simple dual task condition drivers were unable to perform the lane change task at baseline level (F(1,11)=7.5, p<.019). The complexity of the search (F(1,11)=12.5, p<.005) and display size (F(1,11)=5.7, p<.036) reached significance as well as the interaction between the two conditions (F(1,11)=9.0, p<.012). Effects showed an increase of the deviation of the ideal lane keeping with increased set size and conjunction search (see figure 4). The variance of steering wheel angle is reduced as an effect of dual task but this measure showed no significant effects of the visual search manipulations. Participants were able to keep a constant speed of 60 km/h during the whole experiment.

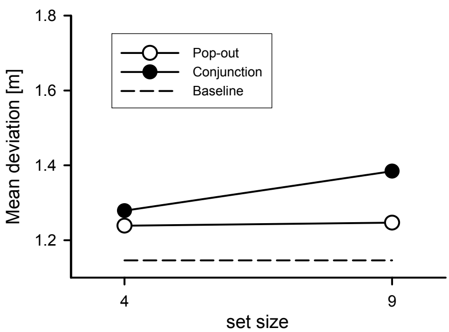

Fig.4. Mean deviation from the normative model for single task baseline driving and driving with different visual search conditions.

Table 1. Performance measures of the visual search task

	Dual Task	Dual-Single difference	p value
RT (ms)	1359 (39.3)	85.9 (37.0)	.063
Error (%)	10.6 (1.1)	2.1 (0.8)	.030
Misses	13.4 (2.7)	9.1 (2.1)	<.001
False alarms	20.4 (3.4)	-1.3 (2.6)	n.s.

Note: Displayed are the mean and standard error. Performance measures on dual task minus single task are given and the paired t-test of this dual vs. single task difference.

4 Discussion

People are fairly good at performing multiple task at the same time when one of the task is automated or highly trained or when coping mechanisms can be applied when task performance is threatened One of the common adaptations seen while driving is to reduce the speed to allow more time for decision making [9, 12, 21, 27]. Because the speed in the experiment was fixed there was no possiblity to compensate for high task demand by reducing the speed. The results of this experiment showed that drivers were unable to continue performing the driving task adequately at baseline level in the dual task condition. Apparently they could not or at least did not sufficiently prioritise the lane change task. Like in the HASTE studies [20] where higher complexity of the visual search task resulted in a large deviation of the lateral positioning on the road, the performance on the lane change task decreased, as was shown in the mean deviation from the normative model. The driving decrement was found even for the most simple search displays containing only four elements with a pop-out target based on colour or orientation. The visual search task performance showed was in accordance with the literature [7, 24, 25, 29], i.e. almost no increase in RT or errors for pop-out displays when set size increases, but a large increase of RT and errors with setsize for conjunction displays. The visual search task also affected the mean deviation of the driving task. Participants were unable to perform the secondary, visual search task at baseline level while driving making substantially more errors. Although there was only a trend ($p<.063$) showing that reaction time increased in the dual task condition, the number of errors increased most strongly with large conjunction displays. The amount of errors could be attributed to the increase of the number of misses. A likely explanation for the number of errors is that the participants did not have enough time to inspect the visual display for the target.

Although it is not directly verifiable it could be the case that the larger mean deviation from the ideal driving track resulted from participants spending a larger amount of their time looking at the visual search display or taking a long time switching between the two tasks. To minimize the physical switching distances between two objects of visual attention, head-up displays (HUDs) have been introduced into the modern automobile. The benefit of this technology is that it decreases eyes-off-the-road and accommodation time [16], although there are also some concerns about the cluttering of information [26]. A follow-up of the present experiment is currently being performed to investigate the use of a HUD to verify if the performance decrease in the driving task can be attributed to the time that the participants spend looking on the display as opposed to divided attention. Another follow up on this study will focus on the elderly driver because they could be especially vulnerable to dual task interference, having motoric perceptual and cognitive functions decline due to normal ageing which affects driving [2, 20].

When using a laboratory driving task to measure the driving performance it should be considered that this environment is artificial and can give a false impression of driving performance. Further results can not be assumed to transfer exactly to driving on the road. It can be concluded that when participants can not adapt their speed, dual task performance decreases when displays require conjunction search and a large number of elements are displayed. Displays with conjunction features forcing inefficient search should be avoided, because reaction time increases and in the dual task situation the amount of errors increases drastically, and at least simulated driving performance is worsened.

5 Acknowledgments

This study was funded by a grant for early stage researchers in the HUMAN-centred design for Information Society Technologies EU-project (HUMANIST; reference number 507420). We would like to thank two anonymous reviewers for their useful comments.

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