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EFFECTS OF VISUAL AND COGNITIVE DISTRACTION ON LANE CHANGE TEST PERFORMANCE

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Summary: Driver errors related to visual and cognitive distraction were studied in the context of the Lane Change Test (LCT). New performance metrics were developed in order to capture the specific effects of visual and cognitive distraction. In line with previous research, it was found that the two types of distraction impaired driving in different ways. Visual, but not cognitive, distraction led to reduced path control. By contrast, only cognitive distraction affected detection and recognition/response selection. Theoretical and practical implications of these results are discussed.

INTRODUCTION

It is well known that driver distraction is one of the most important accident-causing factors (Klauer et al., 2006). Understanding how distraction causes different types of driver errors is a key step towards understanding the potential safety hazards associated with multitasking while driving.

A general distinction can be made between visual distraction ("eyes off road") and cognitive distraction ("mind off road"). Visual diversion from the forward roadway has been shown to impair event detection performance (Lamble, Laakso and Summala, 1999), an effect that has also been strongly linked to real accidents and incidents (Klauer et al., 2006). Visual distraction has also been shown to induce reduced path control in terms of increased lane keeping variation (e.g., Engström, Johansson and Östlund, 2005). Cognitive distraction, e.g., due to cell phone conversation, impairs detection performance, but also recognition and/or response selection (Recarte and Nunes, 2003; Strayer and Drews, in press). Thus, even if a stimulus is detected (as evidenced, for example, by a glance towards it), cognitive distraction may prevent the stimulus from being correctly recognised or adequately responded to. In contrast to visual distraction, cognitive distraction does not seem to impair path control. Rather, it has been shown that cognitive distraction sometimes even *improves* path control, in terms of reduced lane keeping variation (Brookhuis, de Vries and de Ward, 1991; Östlund et al., 2004; Engström et al., 2005).

In the present study, the effects of visual and cognitive distraction on driving performance were further analysed in the context of the Lane Change Test (LCT; Mattes, 2003). The LCT is an increasingly popular method for driver distraction assessment, currently subject to ISO standardisation (ISO, 2007). The basic idea behind the LCT is to assess the effects of distraction in terms of the performance of lane changes commanded by road signs in simulated driving (see below for a more detailed description of the method). LCT performance is generally assessed in terms of the mean deviation from a normative lane change path, a metric that has proven strongly sensitive to both visual and cognitive distraction (Mattes, 2003).

Given the empirical results reviewed above, it could be expected that visual and cognitive tasks affect lane change performance differently. In particular, it could be expected that visual tasks would affect both the path control during the lane change and command sign detection. Purely cognitive tasks should have an effect on the detection and/or identification of the command signs, but not affect path control. In the standard version of the LCT, these effects cannot be separated, since poorly controlled and missed lane changes both increase mean deviation from the normative path. The objective of the present study was to investigate these hypotheses, using alternative performance metrics. A further goal was to obtain a more detailed understanding of the nature of the errors caused by visual and cognitive distraction by means of qualitative analysis of the raw lane change data.

METHOD

The present study was based on re-analysis of LCT data originally collected by DaimlerChrysler in Stuttgart, Germany. The original study was designed to investigate the effects of different instructions to subjects and methods for presenting the command signs. The present analysis used a subset of this data, involving 30 subjects for which the same instructions and sign presentation method were used (see below).

Subjects

Subject characteristics were only available for the entire data set (70 subjects). These subjects ranged from 25-66 years of age (mean 44.6; SD 11.1) and had held a driver’s licence for 5-48 years (mean 28.0). The subjects were equally balanced with respect to gender.

The Lane Change Test setup

The LCT involves driving on a three-lane road while regularly being commanded to change lanes by means of roadside signs. The signs also indicate which lane to change to (the target lane). This is illustrated in Figure 1 (left). As mentioned above, the LCT performance is commonly measured in terms of the mean deviation from a normative lane change path (Mattes, 2003), as illustrated in Figure 1 (right). The present data was collected in a relatively simple driving simulator setup, where the subject was positioned in a seating buck and the LCT simulation was shown on a 17” CRT display in front of the subject. For presentation of the signs, the “content pop-up” method was employed, where the signs were “turned on” at a pre-defined distance, in this case 40 meters.

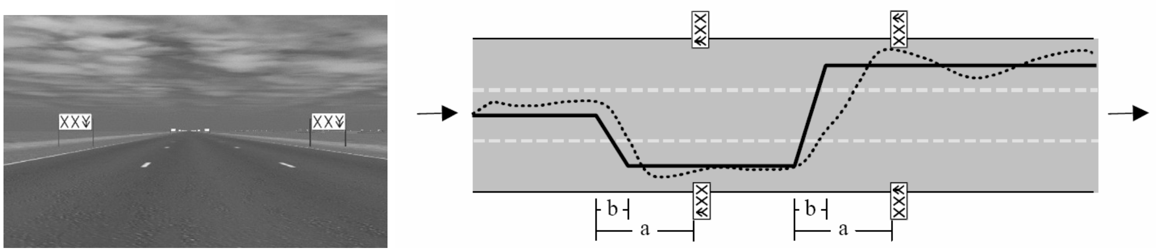

Figure 1. Illustration of the Lane Change Test. Left: The simulated three-lane road with the lane change command signs, in this case indicating a change to the righmost lane. Right: Illustration of the "standard" mean deviation metric.

Ten different tracks were used, each about 2900 meters long. The tracks differed only in the order of, and distance between, signs. The different tracks were used in order to prevent the subjects from learning the lane change sequence. All 6 possible lane change combinations were represented 3 times each per track, resulting in a total of 18 lane changes per track.

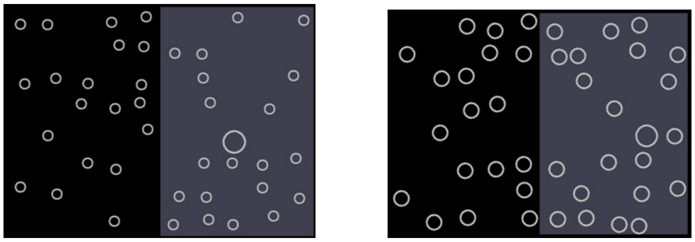

Figure 2. Displays for the Surrogate Reference Tasks, with the two difficulty levels: Easy (left) and Hard (right)

Secondary tasks

The subjects performed a visual-manual and a purely cognitive secondary task, with two difficulty levels for each task. The subject continuously performed the task throughout an entire track. In addition, baseline data were collected where no secondary task was performed. The visual-manual task, known as the Surrogate Reference Task (SuRT) comprised visual search for a target circle among a set of distractors, as illustrated in Figure 2. The SuRT was shown on a 15" TFT display located on the "dashboard" in the seating buck. The subjects used a keypad (located in a position similar to the arm-rest in a real vehicle) to move a grey marker left or right to the area where the target circle appeared and confirmed by pressing a third key. The task difficulty was manipulated by varying the size of the distractor circles (see Figure 2), resulting in two difficulty levels (Visual Easy and Visual Hard). The task was self-paced so that the next display was not presented until the subject had identified a target on the current display.

The cognitive task was counting—up by by 2 in the Easy condition and down by 7 in the Hard condition (Cognitive Easy vs. Cognitive Hard respectively). Thus, the independent variable in the study was Secondary Task, with 5 levels (Baseline, Cognitive Easy, Cognitive Hard, Visual

Easy and Visual Hard). The subjects were instructed to not prioritise either of the tasks (LCT or the secondary task) over the other.

Performance metrics

Since, as mentioned above, the mean deviation metric is not diagnostic of the specific effects investigated in the present analysis, two new performance metrics were defined. First, path control performance was quantified by means of the high-pass filtered (at 0.1 Hz) standard deviation of lateral position (SDLP), calculated for an entire track, where the lateral position was measured relative to the road (and not relative to a specific lane). The purpose of high-pass filtering was to remove the low-frequency effect of the lane changes.

Second, the ability to correctly respond to the lane change command signs was quantified in terms of the *Percent Correct Lane* (PCL) metric, which was computed as follows. For each road segment between two signs, the lane where the vehicle was most frequently positioned was identified. C*onsistent lane choices* were then defined as those cases where the vehicle remained in the lane for more than 75% of the segment. This selected lane was then compared to the correct target lane. For each track, the Percent Correct Lane was then calculated as the fraction of the consistent lane choices that were correct.

RESULTS

The results for path control performance, represented by the high-pass filtered standard deviation (SDLP), are given in Figure 3 (left panel). Compared to baseline, the SDLP increased in the visual task conditions, but was somewhat reduced in the cognitive task conditions. A univariate ANOVA for Secondary Task with Subject as a random factor (equivalent to a repeated measures ANOVA) revealed a significant main effect (F(3, 116) = 9.08, p<.01). Sidak post-hoc tests revealed that only the the visual tasks were significantly different from baseline (p<.001 in both cases).

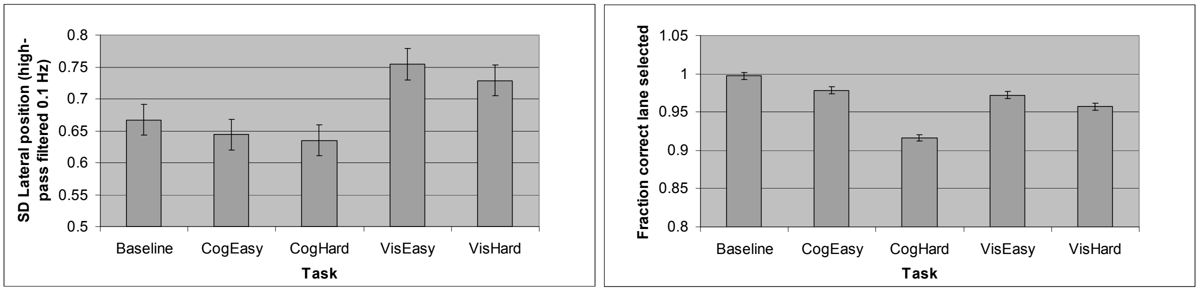

Figure 3. Results per secondary task condition for the two dependent measures: High-pass filtered standard deviation of lateral position (left) and Percent Correct Lane (right). The error bars represent 95% confidence intervals.

The corresponding results for Percent Correct Lane are shown in Figure 3 (right panel). Although all tasks affected lane selection ability somewhat, the strongest effect was found for the Cognitive Hard task, where the PCL dropped from 99.7% (in the baseline condition) to 91.6%. Since the PCL data were strongly non-normally distributed, non-parametric statistics were used for significance testing. A Friedman test revealed a significant main effect of Task $\chi^2(4, N=30) = 32.47$, $p<.001$. Post-hoc testing showed that the only significant difference was that between Baseline and Cognitive Hard ($p<.05$).

In order to obtain some further insight into the types of errors made by the drivers in the different distraction conditions, a qualitative analysis was performed where the raw lane position data for all subjects were plotted as a function of the distance travelled. One such plot was made for each of the ten tracks, and for each task type (see Figure 4 for examples of such plots). Three main types of errors were considered:

1. *Loss of control:* Large rapid changes in lateral position, e.g., due to "overshooting" when arriving in the new lane
2. *No response:* Continuing straight ahead without performing the required lane change (without control loss)
3. *Erroneous response:* Changing to the wrong lane (without control loss)

The three types of errors were subjectively identified by inspection of the plots and counted. The results are given in Table 1.

Table 1. Number and percentage of the different error types for each of the task conditions

	Baseline	**Visual Easy**	**Visual Hard**	**Cognitive Easy**	**Cognitive Hard**
Loss of control	5 (6.7%)	**27 (36%)**	**35 (47%)**	3 (4.0%)	5 (6.7%)
No response	4 (14%)	0 (0%)	4 (14%)	1 (3.6%)	**19 (68%)**
Erroneous response	0 (0%)	0 (0%)	1 (10%)	2 (20%)	**7 (70%)**

As is clear from the table, the great majority of control losses (36%+47%=83%) occurred for the visual tasks. Inspection of the plots revealed that most of the control errors were due to "overshooting" when entering the new lane. By contrast, the majority of lacking and erroneous responses (68% and 70%, respectively) occurred in the Cognitive Hard condition. The typical patterns resulting from visual and cognitive distraction are evident in the plots shown in Figure 4.

DISCUSSION

The results confirmed the previous findings that visual distraction impairs path control. By contrast, lane selection ability, which depends on detection and recognition of the sign and the ability to select the correct response, was only significantly impaired by the Cognitive Hard task. The lack of effect of the visual tasks on detection performance was somewhat unexpected, since visual diversion from the road is well known to impair detection performance (e.g., Lamble et al., 1999). One possible explanation for this is that the lane change signs were highly expected and that the subjects were able to control their visual time-sharing to the extent that the signs were never entirely missed. It may be expected that visual distraction has a more critical impact on the ability to detect unexpected events such as the sudden braking of a lead car. Naturalistic accident and incident analysis has indeed shown that visual diversion from the road combined with the occurrence of an unexpected event is one of the most common factors causing accidents, in particular rear-end collisions (Klauer et al., 2006).

The qualitative analysis showed that the most common error caused by the Cognitive Hard task was of the "no response" type, i.e., continuing straight ahead, apparently without noticing the sign. However, there were also several instances of erroneous responses in which the subject apparently detected the sign, but then made a (smoothly-controlled) lane change to the wrong target lane (see Figure 4). This must be due to a recognition failure, response selection failure or a combination of both. In this case, it did not seem to help much that the signs were expected. This may be because cognitive tasks intefere with the very mechanisms responsible for attention selection (time sharing) and for generating expectations. The types of errors found for cognitive distraction in the present data are functionally similar to running red lights or failing to yield at intersections, and it can be predicted that cognitive distraction is a main factor behind these types of real-world errors.

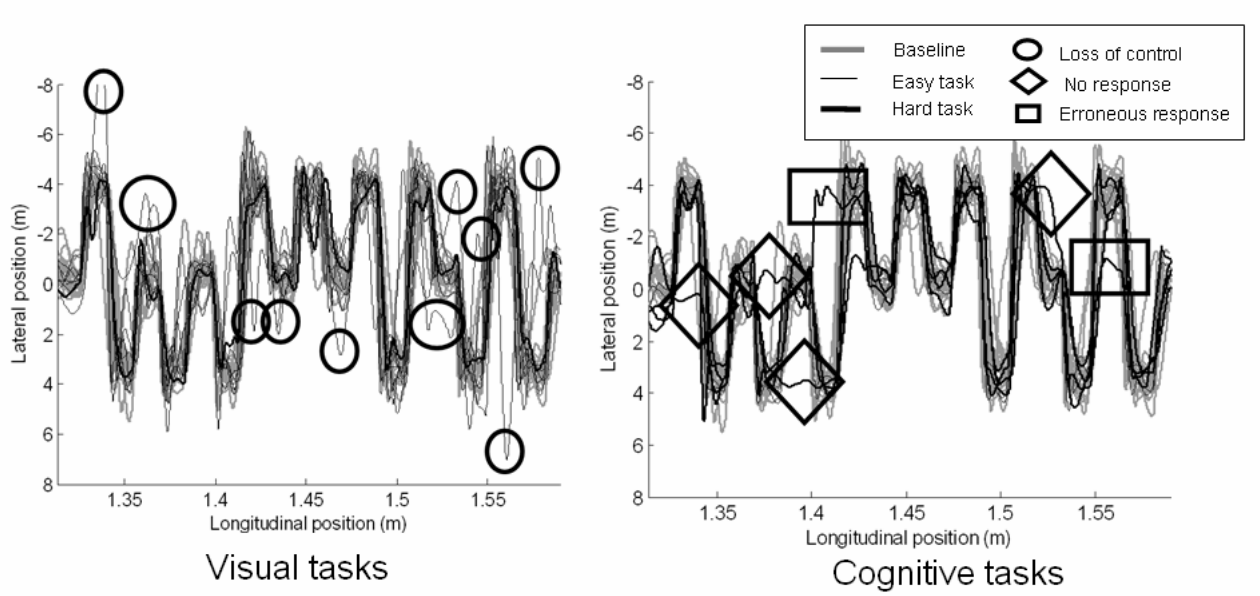

Figure 4. Examples of data plots used for the qualitative analysis of driver errors. Data for visual tasks are shown to the left and cognitive task data in the right panel for a single track (# 5). The task data is plotted on top of the baseline data (which is the same in the two plots). The subjective classification of errors are indicated by the different symbols (see the legend for explanation). The different effects of visual and cognitive distraction are clearly visible from a comparison of the plots.

While the present analysis, as well as many other studies, dealt with the separate effects of visual and cognitive distraction, many real-world secondary tasks include both a visual and a cognitive component. Further research is needed to better understand the relation between visual and cognitive distraction when combined. More research is also needed to investigate the potential interactions between distraction (of both types) and expectancy.

The present results have some important implications for the application of the LCT method to safety-related evaluation of in-vehicle information systems. While the "standard" mean deviation (from a normative path) metric is sensitive to both visual and cognitive distraction, it is not diagnostic of the different types of driver errors demonstrated in the present analysis. Since these errors could be expected to have very different roles in accident production, the mean deviation metric is clearly insufficient as a single safety criterion. For example, it would be problematic to use the standard LCT setup to compare two tasks of different types, e.g., voice dialing and keypad number entry, with respect to their imact on safety. In order to overcome these difficulties, the mean deviation metric could be complemented by other metrics that capture the specific errors related to visual and cognitive load. The two metrics proposed in the present paper may serve as useful starting points.

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