IMPAIRMENT OF LANE CHANGE PERFORMANCE DUE TO DISTRACTION: EFFECT OF EXPERIMENTAL CONTEXTS

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ABSTRACT: This paper aims to evaluate the consistency and sensitivity of the Lane Change Test (LCT), which is subject of a proposed ISO standard. The method aims at estimating driving demand while a secondary task is being performed, by measuring performance degradation on a primary driving-like task. An experiment was conducted in two experimental contexts, a driving simulator and a Personal Computer (including pedals and steering wheel), and with two auditory and two visual-manual secondary tasks. Three performance measures were calculated: mean deviation adapted, correct lane change ratio and lane change initiation. The effect of experimental context was significant. The trajectory, measured by adapted mean deviation, was of better quality on the simulator, while lane changes were initiated earlier on the PC. This difference may be explained by the greater immersion of the driver in the driving scene, which led to easier control of the trajectory in the simulator. Conversely, participants initiated quicker responses to signs when using the PC, to the detriment of trajectory control. The LCT was proven to be sensitive enough to evaluate the driving performance impairment due to the simultaneous performance of various secondary tasks.

1 Introduction

The handling and the use of In-Vehicle Information Systems (IVIS) while driving induces dual-task situations that can lead to driver distraction. Distraction occurs when a driver is delayed “in the recognition of the necessary information to safely maintain the lateral and longitudinal control of the vehicle due to some event, activity, object or person, within or outside the vehicle that compels or tends to induce the driver’s shifting attention away from fundamental driving tasks” [1].

Experimental studies point out differentiated impairment of driver performance for auditory and visual-manual secondary tasks. Performing auditory tasks while driving alters the ability to detect an event, to respond to it correctly and quickly [2-5]. In the case of visual-manual tasks, the ability to control a vehicle is also altered and lane keeping becomes more difficult [6-8].

Distraction has also been shown to increase the risk of having an accident. The National Highway Traffic Safety Administration estimates that at least 25% of police-reported crashes involve some form of driver inattention [9]. For Stutts et al. [10], drivers were distracted at the moment of the crash in 8.3% of the police-reports they analyzed. In-vehicle distraction is also reported as a contributory factor in nearly 2% of the police fatal accident reports investigated by Stevens and Minton [11]. However, these studies certainly underestimate IVIS distraction as the reports are somewhat dated (1995-1999 [10], 1985-1995 [11]). More recently, in the US 100-car naturalistic driving study, Klauer et al. [12] showed that drivers engaged in visually and/or manually complex secondary tasks have a three -times higher near-crash and crash risk than attentive drivers. Epidemiological studies confirm the negative impact of distraction on road safety, showing that conversing by phone while driving (with a hands-free or hand-held phone) is associated with a fourfold increase in crash risk [13-14].

The risk of distraction generated by poorly designed device interfaces is thus of main concern for authorities, designers and researchers. The challenge is to develop simple and low-cost methods to assess the distraction of the Human-Machine Interface at the early stages of the IVIS design process.

The Lane Change Task (LCT) meets these requirements. This method was developed for in-vehicle information systems evaluation in the German project ADAM (Advanced Driver Attention Metrics) [15]. It aims at estimating driver demand while a secondary task is being performed, by measuring performance degradation on a primary driving-like task. This method is currently being discussed in ISO working group TC22/SC13/WG8 as the basis of a standard to access driver demand |16]. The LCT display can be implemented in different experimental contexts (laboratory, driving simulator, mock-up or complete/production vehicle) and should be applicable to all types of interactions with in-vehicle information.

The aim of this paper is to evaluate the consistency and the sensitivity of the LCT. Two main questions are addressed. Firstly, are the test results consistent from one experimental context to another? Secondly, is the test sufficiently sensitive to evaluate distraction effects of tasks with different characteristics? To answer these questions, the LCT was implemented on two experimental contexts: a driving simulator and a low-cost simulator (Personal Computer, pedals and wheel) and with four very different secondary tasks: two auditory tasks and two visual-manual tasks.

2 Method

2.1 Participants

Thirty participants were recruited and split into two equivalent groups of 15 drivers (7 males and 8 females in each group). All participants were aged between 26 and 45 years (mean = 33.8; SD = 5.58). All of them had a driving licence and reported driving at least 5,000 kilometres per year. All stated that they drove several times each week.

All participants were used to using a mobile phone in everyday life (for more than 7 years on average; SD = 2.58). Most of them also stated they used their phone while driving, at least occasionally. All but one stated that they often tuned the radio or dealt with a CD player while driving. None of them had previous experience of the LCT.

2.2 Procedure and design

Each group of 15 drivers performed the experiment in two sessions: one on a driving simulator and the other on a Personal Computer (PC). One group began with the PC condition (Order 1: PC 1^{st} – Simulator 2^{nd}) and the other with the driving simulator condition (Order 2: Simulator 1^{st} - PC 2^{nd}). In between the two sessions, there was a two week break.

On arrival, participants filled in a personal data questionnaire. They were then given written instructions explaining the experiment. To begin each session, participants performed a learning phase consisting of four runs without any added task to enable them to become familiar with the LCT. The experiment itself always began and ended with a run without an added task. Such a run was also performed in the middle. These three runs provided the reference data.

Four added tasks were also performed in four different orders to limit potential task order effects. Each task was first executed without the LCT during about 90 seconds, to let participants get acquainted with it. Participants were then asked to estimate its level of difficulty, by using a scale from 0 (no difficulty) to 10 (very difficult). They were then invited to perform the task with the LCT. After a first run, to ensure that the participants had understood the instructions, their performance was registered. At the end, they had to estimate the difficulty level of the task concurrently executed with LCT, using the same scale.

2.2.1 Driving context

For both sessions, the primary task was the LCT simulated driving task, which involved driving along a straight 3-lane road at a constant speed of 60 km/h. Participants were asked to use the steering wheel to maintain the vehicle position in the centre of the indicated lane. Lane change signs appeared on both sides of the simulated road to inform the drivers of the requirement to change lanes. The signs were always visible but blank, until the lane change instruction was given at a distance of 40 m before the sign position. Participants performed 18 changes resulting in a duration of about 180 s per run (3,000 m).

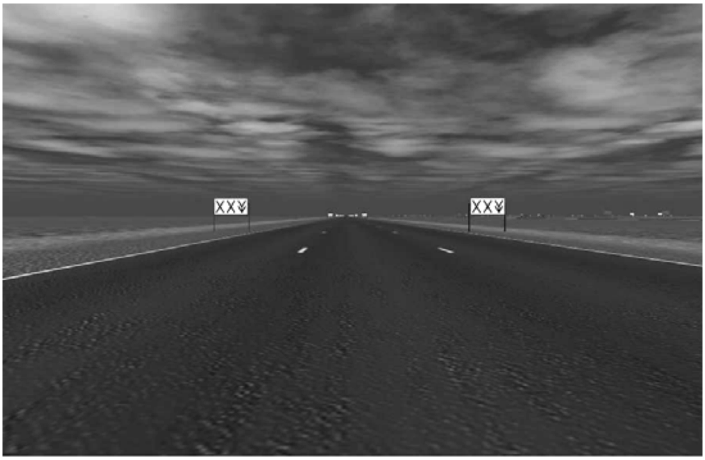


Fig.1. The LCT track

The simulator session was conducted on the INRETS fixed base simulator in Lyon, which had a front screen with a horizontal visual field of 50°. The car body was a Renault Espace with a manual gearbox and all the standard passenger compartment features, displays and controls. Software, conforming to the ISO draft standard, was developed by the INRETS-MSIS team. Checks were carried out in order to ensure a perfect correspondence between this software and the LCT developed in the ADAM project [15].

The same software was used for the PC session, which was carried out on a Personal Computer equipped with a Logitech “Gaming steering wheel and pedals MOMO". The parameters of the transfer function between wheel and vehicle were adjusted in order to make PC and simulator conditions comparable. However the force feedback steering as well as the size of the wheel remained different. The horizontal visual field was between 29° and 34°. Such a configuration is very simple and not expensive making it possible to set up an experiment very easily.

2.2.2 Secondary tasks

Two types of secondary tasks were performed: 2 auditory ones and 2 visual manual ones.

Auditory tasks:

The first one (AT1) consisted of a series of statements pronounced by an experimenter. The participants had to listen to each statement, to repeat it, and to answer “Yes” if it was true, and “No” if it was false. For example: “Alice, my mother in law is younger than her mother Martine” to which participants had to respond “Yes”. Each assertion was randomly presented so that each driver had a single series.

The second task (AT2) involved inventing sentences by creating a chain. To begin with, the participants were given a first sentence comparing animals. They then used the last word of the sentence to create the following one. For example: “A horse is taller than a rat”, “a rat is smaller than an elephant”...

Visual manual tasks:

To perform the visual-manual tasks a screen was placed on the dashboard (simulator condition) or fixed on the table (PC condition). Position and size recommended by the ISO draft standard were respected for each display. A numeric keypad was laid out under the screen so that the driver could carry out the commands related to the two tasks (Figure 2a and 2b).

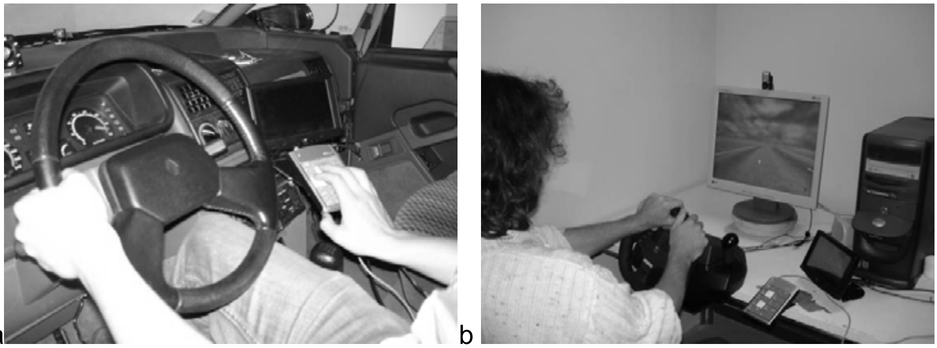
a  b

Fig.2. LCT equipment set up in the simulator condition (a) and the PC condition (b)

The first visual-manual task (VM1) was the Surrogate Reference Task (SuRT). The objective was to look at a screen and to locate a circle among distractors (smaller circles). To select the target, the participants moved a cursor to the relevant zone by using right and left arrows. Then a button allowed them to validate the choice and a new configuration was given by the system. Three levels of difficulty could be activated. All drivers performed the “difficult” level (Figure 3).

The second task (VM2) was the Critical Tracking Test (CTT) designed by Dynamic Research (Figure 4). This task was of interest because the driver did not control its evolution. Participants were faced with a moving black line. To begin with, this line was displayed in the centre of the screen but then went up and down. The objective was to keep it as close as possible to the centre part of the screen, by using the up and down arrows of a keypad. Various difficulty levels could be activated. All drivers performed an easy level (lambda = 1, gain = 20).

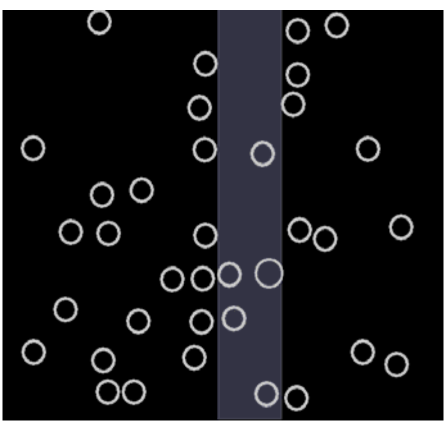


Fig.3. Display for the SuRT with difficult level

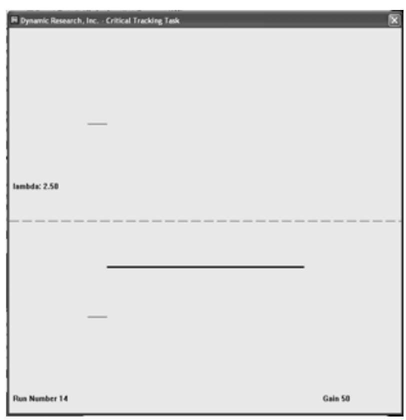


Fig.4. Display for CTT

2.3 Data analysis

2.3.1 Performance measurement

First, **subjective evaluation of the task difficulty** was assessed, by asking the participants to estimate on a 0-10 scale the level of difficulty of each task, while performed alone, and then while performed concurrently with the LCT.

Three measures of performance were also calculated:

- **The Mean Deviation Adapted**: as specified in the LCT ISO draft, the driving performance is mainly evaluated by the driver's mean deviation obtained for each run as compared with a normative trajectory. However, the use of a unique model for all drivers has been discussed and a new model is also being proposed [16-17]. The purpose is to define a reference lane change trajectory for each driver based on his/her baseline runs. This driver-tailored reference was used to calculate the mean deviation adapted.
- **The ratio of correct lane changes** indicated the correctness of the responses to lane change signs. Between two lane change signs an observational zone was defined to determine the lane where the vehicle was most frequently positioned. If this lane corresponded to the sign indication, the lane change was considered as correct [16][18].
- **The lane change initiation** corresponded to the distance between the lane change sign and the distance at which the driver actually initiated it [19]. The calculation only applied to correct lane changes, as determined by the method described above.

2.3.2 Statistical procedure

One-Way Repeated Measures Analyses of Variance ANOVAs were carried out to analyze the data. The experimental design included one between-subjects factor, the Session order (Order 1: PC1st_Simulator2nd; Order 2: Simulator1st _PC2nd) and two within-subjects factors: the Experimental contexts (PC and Simulator) and the Tasks (Reference, AT1, AT2, VM1 and VM2). Paired comparisons were then computed with the Fischer LSD (Least Significant Difference) test. For non-normally distributed data, non-parametric statistics were used for significance testing. For both analyses, a significance threshold of 0.05 was accepted ($p < 5\%$). The statistical procedures were performed with SPSS.

3 Results

3.1 Subjective evaluation of the task difficulty

In terms of subjective evaluation of the task difficulty (Figure 5[1]), no significant difference was found between the two session orders (PC 1st–Simulator 2nd / Simulator 1st-PC 2nd) - neither for the tasks being executed alone [F(1,

[1] Whisker lines on figures 5 to 8 represent the standard deviation of each variable.

28) = 2.049, p = 0.163], nor for the tasks being executed with the LCT [F(1, 28) = 0.728, p = 0.401].

No experimental context effect was found; the subjective evaluation for a given task did not significantly differ from the simulator condition to the PC condition, when the tasks were executed alone [F(1, 28) = 0.041, p = 0.841] and when the tasks were executed with LCT [F(1, 28) = 0.231, p = 0.635].

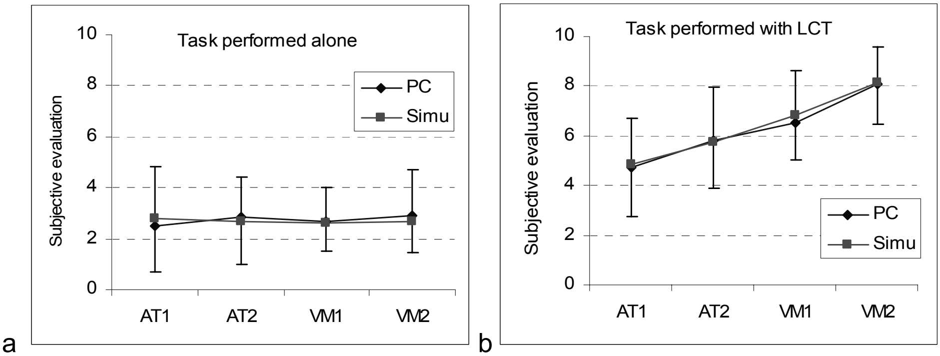


Fig.5. Subjective evaluation of the task difficulty executed alone (a) or with LCT (b)

When executed alone, the task difficulty was not significantly different from one task to another [F(3, 28) = 0.112, p = 0.953]. When performed concurrently with LCT, the tasks appeared to have significantly different subjective levels of difficulty [F(3, 28) = 28.612, p < 0.001]. Paired comparisons computed with the Fischer LSD showed that all tasks differ significantly in terms of level of subjective difficulty given by the participants [p < 0.005]. The tasks can then be sorted, as follows, from the easiest to the most difficult: AT1, AT2, VM1 and VM2.

3.2 Mean deviation adapted

For the measure mean deviation adapted (Figure 6), no significant difference was found between the two session orders (PC 1st–Simulator 2nd / Simulator 1st-PC 2nd) [F(1, 28) = 1.053, p = 0.314].

The analysis yielded a global experimental context effect; the mean deviation obtained in the simulator condition was significantly lower than in the PC condition. The trajectory was thus of better quality in the simulator condition [F(1, 28) = 45.217, p < 0.001].

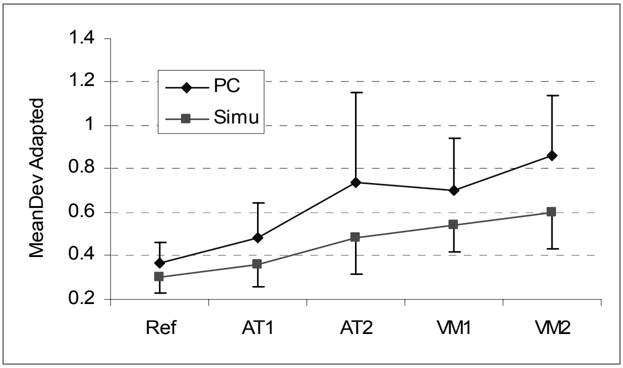


Fig.6. Mean deviation adapted for each task and each experimental context

The mean adapted deviation was also significantly different according to the tasks [$F(4, 28) = 50.736$, $p < 0.001$]. Paired comparisons computed with the Fischer LSD showed that all tasks except AT2 and VM1 differed significantly in terms of mean deviation [$p < 0.005$]. The mean deviation for the Reference appeared to be significantly lower than for all other tasks and mean deviation for VM2 was higher than for all other tasks. AT2 and VM1 were in an intermediate position.

However, a significant interaction was registered between experimental contexts and tasks [$F(4, 112) = 5.489$, $p < 0.001$], showing the effect of the context on the distractive impact level of the tasks, especially on AT2 and VM1.

3.3 Correctness of the lane change

The ratio of correct lane changes was then computed for each task in each experimental context (Figure 7). Since the ratios were not normally distributed, non-parametric statistics were used for significance testing.

No significant difference was found between the two session orders (PC 1st– Simulator 2nd / Simulator 1st-PC 2nd) [$U(1, N=30) = 106.5$, $p = 0.806$].

The analysis yielded a significant effect of experimental context, showing ratios were higher in the simulator condition than in the PC condition [$Z(1, N=30) = -2.738$, $p = 0.006$].

A Friedman test revealed a significant main effect of the Tasks [$\chi^2(4, N=30) = 72.082$, $p<.001$]. Differences in terms of lane change correctness were found between tasks except between Reference and AT1, between AT2 and VM1, and between VM1 and VM2.

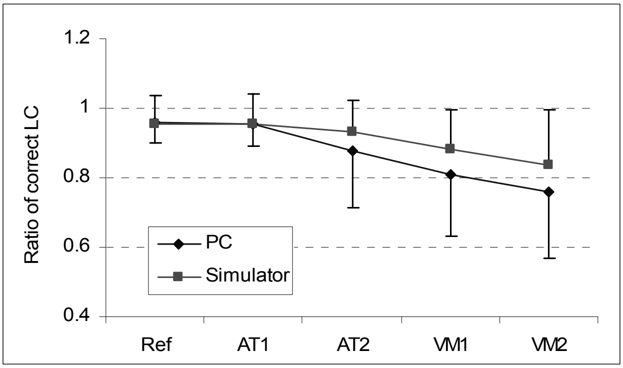


Fig.7. Ratio of correct Lane Change for each task and each experimental context

3.4 Lane change initiation

For the measure lane change initiation, no significant difference was found between the two session orders (PC 1^{st}–Simulator 2^{nd} / Simulator 1^{st}-PC 2^{nd}) [$F(1, 28) = 2.289$, $p = 0.142$].

The analysis yielded a global experimental context effect [$F(1,28) = 12.670$, $p = 0.001$], showing participants took longer to initiate a lane change in the simulator condition than in the PC condition.

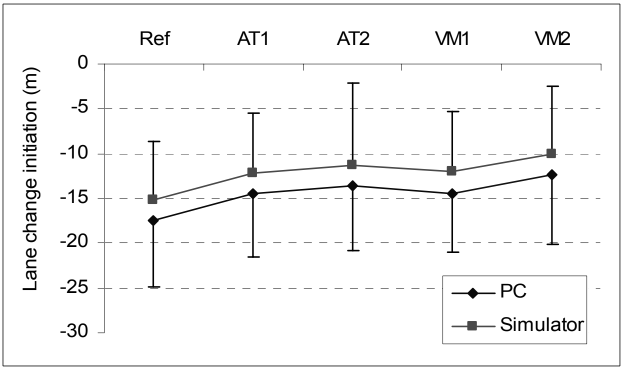


Fig.8. Lane Change initiation for each task and each experimental context

Lane change initiation was also significantly different according to the tasks [$F(4, 28) = 16.977$, $p < 0.001$]. Paired comparisons computed with the Fischer LSD showed that the reference gave significantly earlier LC initiation than all other tasks while VM2 gave later LC initiation than all other tasks, except AT2. No significant difference was found between AT1, AT2 and VM1.

4 Discussion

As the results did not show a significant effect of session order for the four dependent variables, we shall focus on differences between experimental contexts and tasks.

First, an effect of experimental context was obtained, showing differentiated results according to the variables considered. Lane change performance was better in the simulator than in the PC condition. More precisely, mean deviations were smaller and the ratio of correct lane changes was higher. Santos et al. [20] showed similar results by comparing secondary task impacts on driver's lateral control registered in a low cost laboratory driving simulator or a fixed-base driving simulator. We can assume that, in the case of the driving simulator, immersion of the participants in the driving scene is greater. The control of the trajectory is thus easier for the drivers due to the increased visual realism. This assumption is consistent with the findings of Kappé et al. [21] which show that lane-keeping performance is improved by increasing the size of the horizontal visual field and by the display of peripheral information. However, the quality of the force feedback steering was also better in the simulator condition, which may have contributed to the easier control of the trajectory registered in this condition. A similar trend is highlighted by Mourant and Sadhu [22], who showed that the feeling of immersion increases with the realism of force feedback steering. Conversely, participants reacted earlier to the lane change signs in the PC than in the simulator conditions, with distances of lane change initiation being longer. In such a condition, participants seemed to pursue quick sign detection and response, to the detriment of the quality of trajectory control. It is possible that subjects behaved as if they were playing a video game in the PC condition, due to the poorer realism of the driving task.

On the other hand, distractive effects of the four secondary tasks have been evaluated with respect to their modalities: auditory or visual-manual and with respect to their nature:

- establishment of comparative judgement (AT1)
- production of comparative sentence (AT2)
- location of target among distractors (VM1)
- realisation of a tracking test (VM2)

If executed alone, the four tasks were evaluated as being of a similarly low level of difficulty; it was not the same in the dual task condition. AT1 was evaluated as being the least distractive task, VM2 as the most distractive one, while AT2 and VM1 were evaluated at an intermediate level. Such a classification was confirmed with the performance measures. The LCT method thus permits the evaluation of the distractive impact of tasks of different characteristics. The method is sensitive enough to evaluate driving performance impairment due to auditory tasks even in the case of an easy one such as AT1. Moreover, if AT1 and AT2 were both concerned with comparative judgements and thus presented some similarities, their reported difficulty and performance impairments were not of the same level. This could be explained by the necessity of producing complex sentences in the case of AT2. The LCT method also permitted the differentiation of distraction induced by two different visual-manual tasks. Both tasks differed with respect to participants' involvement in the control of their execution. In the case of VM1, the drivers controlled the pace of the display. On the other hand, VM2 consisted of the stabilization of an unstable component. Changes in the task were thus unforeseen and out of their control, then required continuous reactions. These results highlight the joint effect of interface modality and task nature on distraction.

Lastly, this study showed that the three driving performance measures were affected by the experimental context even if the four tasks were organised into a similar hierarchy. This result raises some questions about the possibility of comparing distractive levels obtained in different experimental contexts. It is thus necessary for each experiment to describe the equipment set up and to use a set of reference tasks, in order to be better able to compare experiments.

5 References

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