Occurrence of Secondary Tasks and Quality of Lane Changes

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Abstract. Methods to assess driving degradation due to driver distraction are currently discussed and defined by international standardization groups. A simulator experiment involving 17 participants was conducted to assess the reliability and relevance of one of these methods (Lane Change Test) to discriminate between secondary tasks. In addition to varying age groups, vehicles and secondary tasks, the protocol was also varied to assess the impact of the instruction occurrence and its possible conflict with primary task performance. Results show the limitations of the main parameter proposed by the method (lateral deviation) and question the reliability of the method in its current form. Additional indicators seem necessary to make sense of the respective impact of the varied conditions. Surprisingly, the impact of the instruction occurrence is very limited, apparently because individual strategies have more impact than situations differences.

Keywords: Driver distraction, driving performance, Lane Change Test, secondary tasks, simulator experiment.

1 Introduction

With the continuous development of in-vehicles comfort, information and assistance systems, car manufacturers are facing series of antagonistic demands. First, the consumer demand for new technologies and innovations is counterbalanced with regulation authorities objectives to ensure a robust integration and a cautious usage of these systems. Second, the new applications aiming to reduce driver load (e.g. navigation systems) actually increase the risks of errors in introducing new sources of distraction.

The usage of in-vehicle systems while driving increases the multitasks demand and raises the question of efficient resources management enabling overall safety to be maintained. Typically, navigation systems designed to guide the driver between destinations require extensive and complex set-up, not to mention real-time follow-up

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of visual and/or verbal instructions. Even though these attractive systems provide benefits (comfort, social image, reduced risks of distraction due to map reading while driving), their impact on driver loss of attention and on safety needs to be assessed.

Involving the combination of multiple manual and cognitive resources, driving requires the driver to allocate appropriately and efficiently his/her limited capacities [1]. In addition to the motor skills required to maneuver and control a vehicle, cognitive resources are essential to perform driving-related tasks such as information perception, event detection, problem solving and decision making. Continuous monitoring of the surroundings (including through rear and side view mirrors), essential to maintain situation awareness requires the driver to focus attention to the road scene. Any glance inside the vehicle, i.e. away from the road scene, reduces the driver opportunity to detect hazards and handle them safely. Wickens [2] proposed a multiple resources management model to describe how driver could simultaneously handle this variety of tasks. This model highlights the driver ability to use concurrently different modalities (visual, auditory, tactile, …) to apprehend situation demand and perform efficiently and safely the driving tasks. Based on this theory, the impact of display clutter, location, modality on driver distraction has been measured using various metrics: scanning patterns, hazard detection time, quality of lane keeping, secondary task quality ([1], [3], [4], [5]). Some computational models are also currently investigated to predict the amount of interference that will occur between two or more tasks performed concurrently.

The recent naturalistic study conducted in US suggested that driver's glances away from the forward roadway potentially contribute to a much greater percentage of events than has been previously thought, with 78% of the crashes and 65% of the near crashes [6]. Secondary-task distraction contributed to over 22 percent of all crashes and near-crashes [7], which is in-line with recent French results [8]. Whereas research studies are essential to provide a better understanding and knowledge of the driver (e.g. strategies, capabilities and limitations), car manufacturers face a pressing need for fast, simple, cost-effective and reliable method to measure the potential impact of new in-vehicle systems on driver distraction and safety. Risks induced by driver distraction vary with the type, timing, intensity, frequency and duration of this distraction. It is essential to understand these factors and their mutual influences. Several methods currently discussed at an international level (ISO TC22/SC13/WG8) are intended as "tools to help system designers ensure that the intended benefits outweigh the risks of devices and features that are meant to be used while driving" [9]. In this context, a method denoted Lane Change Test (LCT) aims at measuring quantitatively the degradation of driving performance induced by secondary tasks. Previous experiments conducted in the LAB proposed improvements in terms of experimental protocol (e.g. vehicle-based protocol) and analysis (e.g. individual reference trajectory, eye-tracker data, position on lane).

To build on efforts to assess the LCT method ([10], [11]) a new experiment was conducted on a simulator in autumn 2006. The main objectives were to assess the relevance and robustness of the LCT method, to identify its main limitations and if necessary refine it.

2 Method

2.1 Participants

Seventeen participants of two age groups ([25-54] and [60-70]) were recruited through public notice. All had valid driver's licences, a minimum of 4 years of driving (mean=28 and max=48) and drive on average 16000 kilometers per year (min=5000 and max=25000). The same participants were involved in the four successive sessions.

2.2 Apparatus

Equipment. Four different production vehicles were tested. Attention was paid to ensure that the systems tested were comparable in terms of functions provided and modalities of interaction (input and display). The vehicles were positioned in front of a 2x3 meters video screen where the driving scene was projected. Front wheels of the test vehicle were placed on swiveling plates to reduce friction to ground. Video camera were placed inside the vehicle to collect three complementary views: driver's face, over the shoulder view and HMI view. Additional markers were provided to enable the experimenter to highlight events of interest (e.g. beginning / end of secondary tasks). Scenario and recording (system and video) were automatically launched from the experimenter workplace. For a calibration task, a dedicated 15" monitor was positioned on the right side of the route scene and a simplified keyboard (limited to arrow keys) was used to perform the designation and selection task. When not necessary this display was removed from the scene. For the other secondary tasks (radio manipulation, interaction with the navigation system), displays available in the tested vehicles were used.

LCT Software and task. The tool developed in the context of the ADAM project [12] was used to perform the Lane Change Test. The Lane Change Test (LCT) is a simple laboratory dynamic dual-task method that aims to quantitatively measure performance degradation on a primary driving-like task while a secondary task is being performed. The LCT comprises a simple driving simulation that requires a test participant to drive along a straight 3-lane road at a constant, system controlled, speed of 60km/h. Participants are instructed in which of the lanes to drive by signs that appear at regular intervals on both sides of the road. Participants use the vehicle steering wheel to maintain the position of the simulator vehicle in the centre of the indicated lane and are prompted to change lanes according to the instructions on the signs. The only visual feedback the participants get is the front view (i.e. no rear nor side view provided in mirrors). Engine sound was simulated to increase situation realism. The scene consisted of a series of 3 km test tracks, with lane change signs displayed every 150m. Participants had to perform maneuvers as quickly and efficiently as possible. Actions on the steering wheels were instrumented and transmitted to the simulation tool in order to reproduce on screen lateral changes.

2.3 Experimental Design

Run plan. For each vehicle tested, the experiment used a 2 (age group: medium, senior) x 5 (secondary task: none, calibration, radio scrolling, radio list and navigation) x 3 (occurrence: at the sign, 50m before, 50m after) repeated measures design.

Secondary tasks. To enable comparison between LCT studies, the Surrogate Reference Task (SuRT) was used as a calibration task (standardized reference). It required the participants to locate a target among visually similar distractors (visual demand) and then select the portion of screen containing the target (manual demand). In addition, three other tasks were tested in each of the four vehicles: radio frequency scrolling, radio station selection and destination entry in the navigation system. The radio scroll and the radio list were very similar in all vehicles. The navigation tasks differed both in terms of navigation in menus and accessibility of interaction devices: input devices were located on the front panel for vehicles 1, 2 and 4 and on the right side of the driver for vehicle 3. To avoid boredom, radio and navigation tasks were mixed and occurred between 1 and 2 times each within each track. To ensure comparable conditions between subjects and between successive vehicles, secondary tasks instructions were pre-recorded and automatically issued at a same moment defined in distance to lane change sign (-50m, 0m or +50m). The three occurrence correspond to the appearance of the lane change sign, the end of the lane change and the maintaining of the trajectory.

Programme. Prior to the experimentation, all participants tested the experimental set-up, essentially to ensure that none of them suffered from the simulator sickness. Four different sessions of two weeks each were organized between September and November 2006. For each vehicle, every participant went through sessions of two hours, including training, measures and debriefing. Each of the four sessions began with a training period, whose objective was for the participants to become familiar with both the primary (drive and change lanes) and the secondary tasks. For the measured runs, the participants drove along 10 successive tracks: without secondary task (tracks 1 and 10), with calibration task (tracks 2 and 9) and with mixed secondary tasks (tracks 3 to 8).

Expected LCT output. The method was expected to be sensitive to *secondary tasks* (less degradation with radio than with navigation tasks) and *instruction occurrence* (more degradation before the sign due to disturbance in sign detection). No difference between *vehicles* was assumed, but the method should expected to be too sensitive to *drivers experience* with the simulation tool and consequently not reliable enough to compare successively different vehicles with same participants.

3 Results

The objective and subjective data collected consisted of vehicles parameters, LCT simulator logs, experimenter's markings, audio and video recording of participants' actions and comments, experimenter's observations, interviews and questionnaire items. In the present paper, the focus is on medium age group results.

3.1 Lane Change Task Performance

To reflect the degradation of the lateral control possibly induced by the secondary task, the actual course is compared with a theoretical one. The mean lateral deviation "is the total area between the normative model and driving course (in m2) divided by the distance driven (m)." [9] The mean deviation in lane change was calculated per task in a repeated measures analysis. Typically, measures taken between beginning and end of a task were then summed to obtain a mean per type of task. Comparisons between means were made using 95% confidence intervals. Despite its interest, this normative model seemed too ideal, and often far from actual performances. A more accurate deviation was calculated on the basis of participants average lane changes (initiation of the change, rate of change) in the baseline condition. Similar trends were observed with normative and adapted deviations, but deviation values were smaller when using the adapted model (Fig. 1 left). Participants showed a greater mean deviation when performing two tasks (e.g. driving and manipulating radio) than when performing the baseline condition (driving without secondary task) [$F(4,414)=57.54$, $p<0.001$]. Performances were similar in the drive only and calibration conditions. Mean values of the adapted deviation were similar in all conditions. Surprisingly, the task estimated as the most difficult (navigation) induced less deviation than the two other tasks (radio list and radio scroll). The participants showed a larger normative deviation when scrolling frequencies, but no difference between tasks in terms of adapted deviation. The mean deviation metric (normative and adapted) does not seem sensitive enough to discriminate between tasks within the medium group. No significant difference between the vehicles is observed.

The impact of the instruction occurrence varies along with the type of secondary task: the worst result (larger deviation) is obtained with the "0" occurrence for the

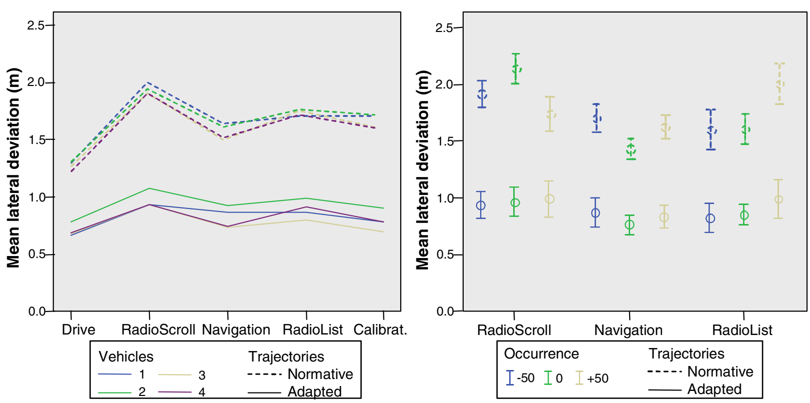

Fig. 1. Lateral deviation as a function of vehicle (left) and instruction occurrence (right) for the medium age group

radio scroll and “+50” for the radio list. The best result is obtained with the “-50” for the navigation (Fig. 1 right). The results suggest that each secondary task affects differently the various dimensions of the primary task (e.g. sign detection, change initiation, change maneuver, position adjustment), each corresponding to a specific position on the trajectory.

3.2 Secondary Task Performance

Even though the standardized LCT is limited to the analysis of the deviation metric, it was decided to consider additional indicators and assess their potential added value. The secondary tasks were characterized in terms of their duration and latency and compared according to the age, vehicle and occurrence factors. To calculate duration and latency, the start of action was defined as the first action on the device. The navigation task was the longest (between 50 and 60 seconds), while radio tasks were much shorter (20-30 seconds for the radio scroll and 15-20 seconds for the radio list). Participants showed the largest latency for the radio scroll task, possibly due to the structure of the instruction, with the relevant information at the end of the message (Fig. 2). The latency values were larger with the first vehicle. This suggests a learning effect: the participants gradually learnt to anticipate the tasks, initiating actions even before the end of the instructions. Both duration and latency of the navigation task were increased with the “- 50” condition (Fig. 3). Two explanations are proposed: (i) one can assume that in this condition, participants waited for the sign to appear before initiating this long task; (ii) this could reflect the strategy used to perform the task, corresponding to interruptions to focus momentarily on the lane change task. This last point could also explain why the most efficient lane change task performance (reduced deviation) is observed with this navigation task. No other effect of the occurrence on the secondary tasks performance was observed. A possible explanation lies in the differences in individual strategies. Two main categories were identified: “in a hurry”, who initiates the task as soon as the instruction is issued and perform it quickly and “careful” who gives priority to driving, wait for the appropriate not conflicting moment to initiate it, perform it cautiously and occasionally interrupt it. Each instruction occurrence might finally correspond to a different situation on the track for participants according to the strategy they use: “-50” for a “careful” participant might correspond to “0” for a participant “in a hurry”.

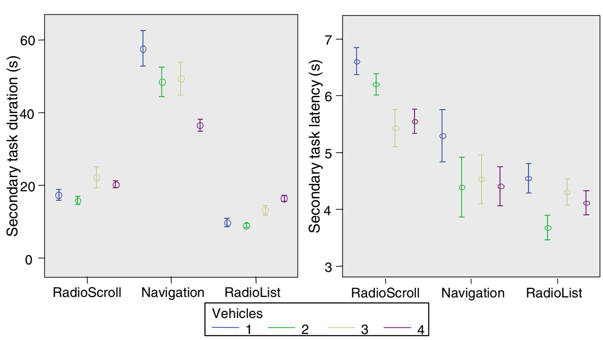

Fig. 2. Duration and latency of secondary tasks, medium age group, all vehicles

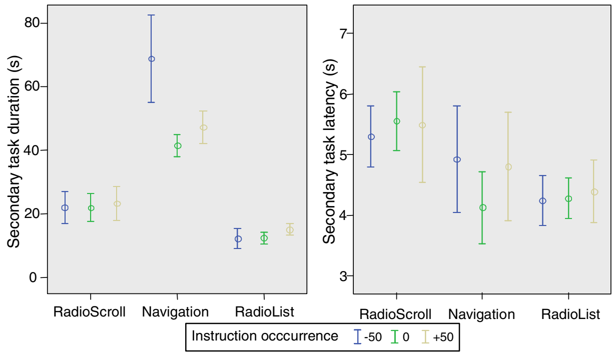

Fig. 3. Duration and latency of secondary tasks, as a function of instruction occurrence, medium age group, vehicle 3

4 Discussion

4.1 Inter-individual Differences

Neither normative nor adapted deviation was sensitive enough to discriminate between tasks and both provided surprising results, with the longest and most complex task measured as the less distractive in terms of driving degradation. This questions the SAE Recommended Practice J2364, commonly known as the 15-Second Rule for Total Task Time or the 15-Second Rule, which specifies the maximum time allowed (15 seconds) for completing a navigation system task involving manual controls and visual displays when the task is performed statically [13]. Latency and duration of secondary tasks provided discrimination between tasks and driver strategies. Observations of the participants practices, combined with a more detailed analysis of the instructions used revealed a major difference. For the radio scroll, the participants had to wait until the end of the message (5 seconds later) to know the frequency and decide on which arrow (up or down) to press, whereas they could initiate actions earlier for the radio list (press on “mode” or “list” button) and for the navigation tasks. The latency in secondary tasks initiation results in a different position on the trajectory, and consequently conflict between different resources allocations. The various strategies observed during the experimentations were consistent with previous findings on cognitive heuristics in multitasking environment [14]. Because of the varied strategies, the moments of occurrence needs to be more precisely characterized for each driver profile in clarifying the expected conflicts (e.g. sign detection, position adjustment, trajectory maintaining). Typically, the latency of radio scroll task results in 10 meters “delay”, which may correspond, with the second occurrence (“0”) and a “hurry” profile, to the most demanding task in terms of visual and manual control. In terms of visual load, the driver needs to look both at the radio device to read the frequencies and at the road to appropriately end the lane change and adjust his/her position on the new lane. In terms of manual load, the driver must both manipulate the radio (press on arrows) and move the steering wheel to adjust position. The duration of tasks also influences strategies: on the one hand, the navigation task, considered by participants as long and complex was usually initiated quickly by the drivers but decomposed in successive independent sub-tasks. This resulted in conflicts with the detection of the change sign in the “-50” occurrence. On the other hand, the radio list, considered as short and simple resulted in lower pressure in the “+50” condition (no sign to detect, no adjustment on lane) and led drivers to literally dive into the task, focusing their whole attention on the radio device. To go a step further, drivers’ eye movements in similar situations should be analysed, as this raises the issue of situation awareness and driver capabilities to detect events and react appropriately.

4.2 Methodological Issues

The observations during experiments, coupled with the analysis of actual trajectories showed compensation actions at the end of secondary tasks. Typically, after the last action (i.e. after the “end” marker), the driver adjusts his/her course to replace the vehicle in the middle of the lane. In the current analysis, those periods are not covered. This raises the question of the definition of beginning and end of secondary tasks and associated periods of analysis. The analysis of secondary tasks latency and duration also raises the issue of the learning process. The gradual reduction of latency suggests that with practice participants get familiar with what is expected and confident with their ability to initiate tasks. Typically, they learn with practice that for navigation and radio list tasks they can initiate actions even before the end of the verbal instructions. This effect questions the involvement of same participants in series of studies investigating successively different systems. Combined with the observation of different driver strategic profiles (quick versus careful), this raises the issue of participant selection and experiments reproducibility.

Even though the LCT method was never designed to reproduce the reality of driving (but rather to enable comparison between systems), it can be emphasized that the simplified setting limits the driving to the lateral control of the vehicle and the detection of information located in front of the vehicle. The allocation of visual resources observed in the LCT settings and the associated measures of driving degradation need to be put into perspective. Indeed, the impact of the distribution of visual attention between two sources located in front view might be completely inadequate when this attention needs to be split between opposite directions (front versus side or rear). As we could see, even though the LCT indicator (lateral deviation) is not sensitive enough to discriminate among medium age participants, it provides interesting results (longest tasks inducing lesser deviation). Typically, it suggests that the interruptibility of the task is not inherent to the task, but rather reflects a user intention. To improve the analysis and interpretation of results, the method could benefit from additional perspectives. Typically, expert evaluation or user testing of the in-vehicles systems used for secondary tasks could provide relevant information in terms of secondary tasks characterization, strategies and trade-offs implemented in the course of action. The tasks simulated with the LCT tool are realistic in the sense that guidance, lateral control, lane change are real driving tasks. However, the frequency of the tasks is not realistic. The question of generalization of results needs to be questioned. Again, one needs to remember the initial objectives of the method and consider carefully strategies and performances obtained in these conditions. Whereas an improved indicator might enable different design options to be compared it should not be envisaged as a means to evaluate one option per se.

5 Conclusion

The simulator experiment conducted with two age groups (senior and medium) assessed the relevance and the reliability of the LCT method to measure degradation of the driving task due to secondary tasks performance. In addition to varying age groups, vehicles and secondary tasks, the protocol was also varied to assess the impact of the instruction occurrence and its possible conflict with primary task performance. Results show the limitations of the main parameter proposed by the method (lateral deviation) and question the reliability of the method in its current form. Additional indicators seem necessary to make sense of the respective impact of the varied conditions. Surprisingly, the impact of the instruction occurrence is very limited, apparently because inter-individual differences have more effects than the situations differences. The participants seem to implement different strategies according to the specificity of tasks: short tasks induce a "dive in" behavior, with an intense but brief focus on the in-vehicle devices, whereas with longest tasks the driver attention is split between the driving and the secondary task. Beyond understanding what type of deviation is the most acceptable in terms of safety (i.e. between a large but short deviation and a small but long one), the next step will consist in investigating the quality of lane changes performed. To discriminate low quality of lateral control from errors in lane changes (omission or incorrect change), the type and frequency of errors are currently analysed.

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