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Published version:

DOI:10.1016/j.apergo.2011.08.001

Applied Ergonomics,
2012, 43 (3), pp. 486-492. doi:10.1016/j.apergo.2011.08.001

Measuring the effects of visual demand on lateral deviation: A comparison among driver' s performance indicators

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ARTICLE INFO

Article history:
Received 30 May 2010
Accepted 2 August 2011

Keywords:
Driving performance measures
Lane change test
Visual workload

ABSTRACT

In this study we compare the efficacy of three driver's performance indicators based on lateral deviation in detecting significant on-road performance degradations while interacting with a secondary task: the High Frequency Component of steering wheel (HFC), and two indicators described in ISO/DIS 26022 (2007): the Normative and the Adapted Lane Change Test (LCT). Sixteen participants were asked to perform a simulated lane-change task while interacting, when required, with a visual search task with two levels of difficulty. According to predictions, results showed that the Adapted LCT indicator, taking into consideration individual practices in performing the LCT, succeeded in discriminating between single and dual task conditions. Furthermore, this indicator was also able to detect whether the driver was interacting with an easy or a difficult secondary task. Despite predictions, results did not confirm Normative LCT and HFC to be reliable indicators of performance degradation within the simulated LCT.

1. Introduction

Secondary tasks while driving can provide the driver with dangerous additional information, leading to driving performance degradations. We may suppose that some secondary tasks are distracting because of the high visual effort required and the consequent visual workload it generates (e.g. a target search on a map), whereas other tasks are so because of the demanding cognitive processing (e.g. a high complexity phone conversation). The aim of the experiment described in this paper was to evaluate the effectiveness of several driver's performance indicators described in the ISO/DIS 26022 (2007) Road vehicles - Ergonomic aspects of transport information and control systems - Simulated lane change test to assess in-vehicle secondary task demand (ISO/DIS 26022, 2007), currently under approval, in the hope of offering a valid contribution to the review of the standard.

1.1. Background

Driver distraction is defined as attention given to a non-driving related activity, typically to the detriment of driving performance (ISO, 2005). Since IVIS (In-Vehicle Information Systems) devices are becoming more and more common, it has become crucial to determine the effects that those systems may have on drivers' behavior and safety.

Many studies were done, with some relevant findings: the results from the HASTE project (EU 5th framework, 2002-2005) demonstrated the effects of visual distraction on driving performance (Engström et al., 2005; Victor et al., 2005). Visual distraction typically induces a visual time sharing between the road ahead and the system display. During glances to the display, the visual input needed for lateral control is reduced or entirely inhibited: the driver is affected by a temporary lack of steering response, leading to a deteriorated lateral control that enhance the risks of frontal collision. According to Engström et al. (2005), visual secondary tasks led to reduced event detection performance (e.g. increased peripheral detection task response time). During visual tasks, the reduction of lateral control is usually compensated by a speed reduction (Antin et al., 1990; Engström et al., 2005). In order to investigate the effects of visual and cognitive distraction on driving performance many indicators have been identified (Peters et al., 2005):

- Steering performance metrics (Boer, 2000; Boer et al., 2005; McLean and Hoffman, 1975; Nakayama et al., 1999; Östlund et al., 2004; Verwey, 2000);
- Lane keeping metrics (Östlund et al., 2004; Godthelp et al., 1984; Wierwille et al., 1992);
- Speed metrics (Östlund et al., 2004);
- Vehicle following metrics (Brookhuis et al., 1994; Östlund et al., 2004);

- Response time metrics (Green, 1993; Wierwille et al., 1992);
- Lane Change Task metrics (Wierwille et al., 1992);
- Steering grip metrics (Mattes, 2003; Peters et al., 2005).

An indicator reflects driving performance when it detects the behavioral changes caused by the impact of a secondary task. As it emerges from the aforementioned studies, lateral position is one of the most commonly used driving behavior metrics. Mean lateral position is used as a metric of driving strategy, a measure of the driver's choice to drive on a safe path of travel (Gibson and Crooks, 1938). Lateral position variation is influenced by unintentional lateral variations caused by the difficulty to drive completely straight (tracking error). These variations are faster than other variations (Peters et al., 2005; Hollnagel andWoods, 2005) and are therefore efficient indicators.

1.2. Dependent variables

In the present experiment we adopted the Lane Change Test (LCT; Mattes, 2003), a dynamic dual-task method for quantitatively estimating human performance degradation on a primary driving-like task, while a secondary task is being performed. The LCT is applicable to all types of interactions with in-vehicle information, communication, entertainment, control systems, and combinations thereof. Tasks that require speed variations cannot be tested with this method (ISO/DIS 26022, 2007). In the LCT, participants have to drive at a constant system-controlled speed of 60 km/h along a simulated 3-lane straight road displayed on a screen. Simulated vehicle position is controlled by means of a steering wheel. The test can be implemented not only in a driving simulator but also in a laboratory, in a mock-up or in a real vehicle. The goal of LCT is to obtain the value of the deviation between a reference optimal course and the actual driving course of the driver along a predefined track. This deviation reflects a decrease in driver's perception of road rules and in the vehicle lateral control. In our experiment we adopted both the ISO/DIS 26022 (2007) methods to compute specific performance indicators: the Normative LCT performance indicator and the Adapted LCT performance indicator, based on the adapted curve. Furthermore, we tested the efficacy of an indicator based on lateral deviation: the High Frequency Component of steering wheel (HFC). The effect of secondary-task demand is measured by the deviation between a control curve (i.e. the normative or the adapted one) and the real driving path performed by the tester along the assigned track. This deviation measure copes with central aspects of the driving performance: the perception (late perception of the sign or missing a sign), the quality of the maneuver (slow lane change results in larger deviation) and lane keeping quality, which all result in an increased deviation. The mean deviation between the control curve and the real driving path can then be calculated as:

$$\bar{x}_{\text{deviation}} = \frac{1}{S}\sum\left(x_{\text{deviation},i}\left(\frac{y_{i+1}-y_{i-1}}{2}\right)\right) \quad (1)$$

$$x_{\text{deviation},i} = x_{\text{position},i} - x_{\text{control},i} \quad (2)$$

The variable y corresponds to a longitudinal component of the vehicle position on the track and S is the length (meters) of the data segment analyzed. The calculation is done across all data sections, that are relevant for a certain experimental condition. This means that the invalid data segments (e.g. time for instructions by the experimenter) are removed and the remaining valid data is handled as if it was one continuous set of data. The same applies to an experimental design where secondary tasks of one experimental condition are distributed over several experimental runs. The gathered data are then processed by dedicated software in order to calculate the difference between the ideal curve and the observed one. In this study the equation (1) has been computed using both methods described in the ISO/DIS 26022 (2007) to obtain the Normative LCT performance indicator and the Adapted LCT performance indicator.

1.2.1. Normative LCT performance indicator

In the first method, the reference curve is called normative. It represents a curve of fast-lane-changes obtained by assuming a 600 ms driver reaction time (according to ISO/DIS 26022, 2007 it is unlikely that drivers react faster) from the moment the lane-change sign appears on the driving simulator screen to the moment the driver initiates the lane change.

To get the normative curve for each participant an individual lane change start and length (StartLaneChange, LaneChangeLength) and the lateral positions on each lane (AdaptedPosXlane1 for lane 1, AdaptedPosXlane2 for lane 2 and AdaptedPosXlane3 for lane 3) is calculated (Fig. 1). Once the normative curve is computed for the specific track, all drivers' courses are compared to it in order to obtain the related deviation.

1.2.2. Adapted LCT performance indicator

The second method is an enhancement of the former one and it introduces the concept of an adapted curve computed for each driver. It is a new measurement aiming to calculate a reference curve using a recorded trial (i.e. a baseline) where the participant is asked to complete a lane change session without any added secondary-task. In order to obtain the adapted indicator the same two parameters adopted in the normative model are used (StartLaneChange distance and LaneChangeLength) but with the addition of an intermediate variable: the Average Distance. It corresponds to the distance between the lane change sign position and the center of the lane after the lane change has been performed. The adapted reference curve is then obtained in two stages by calculating, firstly, the Average Distance and secondly, the Lane Change Length. The benefits of this method are evident: elaborating and crossing the data from the baseline condition and the control condition allows creating an ideal lane deviation path for every driver considering differences among participants' driving style and making data much more reliable and consistent.

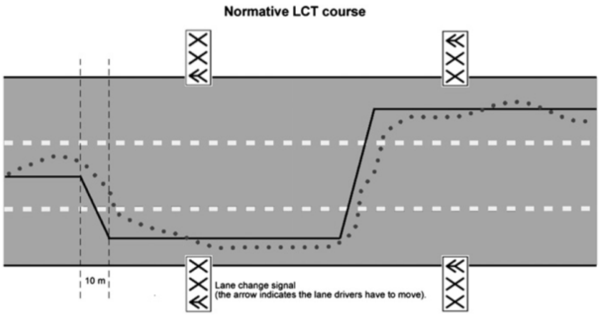

Fig. 1. Normative LCT performance indicator. Solid line: normative curve. Dotted line: driver's course. The fast lane change computed in the normative curve is completed in 10m.

1.2.3. High Frequency Component of steering angle

The primary effects on lateral position variations are drivers' actions on the steering wheel. A detailed analysis of lateral deviation performances can be conducted by focusing on the variation of steering wheel angle by means of a spectral analysis of the steering signal. This involves transforming the signal to the frequency domain (by means of Fourier transform) and analyzing those frequency bands affected by different factors, in this case by the introduction of a secondary task during driving. McLean and Hoffman (1975) found that the frequency content in the 0.35-0.6 Hz band is sensitive to variations in both primary and secondary task load. Thus, the power spectral density (i.e. the area under the spectral curve in the relevant frequency region), may be used as a steering performance indicator. In Östlund et al. (2004) the 0.3-0.6 range was filtered out using a band pass filter and the final metric was obtained by computing the standard deviation of the remaining signal. In most studies on steering frequency, focus has been on the 0-0.6 Hz area of the steering angle spectrum, which has been found to be dominant frequency band for steering activity.

According to the literature mentioned before, the High Frequency Component of steering angle (HFC) was computed as follows:

1. The steering wheel signal was filtered with a low pass filter (Butterworth 2nd order, cut off frequency 0.6 Hz) to eliminate noises in the steering activity. This signal is here called "total activity" (P_{total}).

2. The frequency band of interest (P_{band}) was obtained by further filtering the total activity signal with a high pass filter (Butterworth 2nd order, cut off frequency 0.3 Hz).

3. The HFC value was then calculated as the proportion between the power of the frequency band signal and the total steering activity signal.

The value of the indicator has been computed as follows.

$$\mathrm{HFC} = \frac{P_{\mathrm{band}}}{P_{\mathrm{total}}} \qquad (3)$$

Thanks to its complexity and flexibility the described indicator provides an effective indirect measure of the visual workload.

1.3. Research hypothesis

In the present study we conducted an analysis of Normative LCT, Adapted LCT and HFC indicators aiming to find out a significant relationship between driving performance and visual demand variations induced by the introduction of a secondary on-board task. Thus we expected:

- Normative and Adapted LCT indicators being able to reflect visual workload manipulations, then confirming the objectives of the ISO/DIS 26022 (2007). We expected this significance to be higher for the Adapted LCT, since this indicator includes individual practices of the drivers in performing the driving task.
- HFC indicator, being able to reflect visual workload manipulations since any variations of drivers' visual attention affect the steering wheel frequency variation (Östlund et al., 2004).
- HFC and Adapted LCT indicators would be able to discriminate drivers' lateral performance while executing secondary task requiring different level of visual workload. Regarding HFC, the steering wheel signal in the frequency domain was expected to capture slight lateral variations induced by different levels of visual workload since other sources of variation were filtered.

A laboratory software application was developed to support the analysis of drivers' performances with reference to the normative and adapted curves. The application was based on the ISO/DIS 26022 (2007) specifications and its features include the computation of the normative and adapted curves, the deviation between these curves and the drivers' course and the related performance indicators discussed in the previous sections. Fig. 3 shows the comparison between driver courses and normative curve computed by the software application using data collected by the driving simulator during the test.

2. Method

2.1. Participants

Sixteen participants (13 male, mean age = 31, min = 25, max = 36, SD = 4) were recruited in the University of Modena and Reggio Emilia. All participants had valid Italian driving licenses, a minimum of 6 years of driving experience (max = 18, mean = 13, SD = 4), driving a minimum of 3000 km per year (max = 40,000, mean = 23,000, SD = 10,000), on average 74% of it on a familiar path (min = 10, max = 90, SD = 21). All of them usually use an IVIS while driving.

2.2. Apparatus

2.2.1 Driving Simulator

An Oktal SCANeR II driving simulator was set up to perform the LCT (see section 2.3.3) according to the specifications of the ISO/DIS 26022 (2007). The vehicle position and dynamics are logged by the driving simulator at a frequency of 20 Hz. Data logs are saved as txt files for offline analysis.

2.2.2. Secondary task display settings

A 13 x 17 cm touch screen display (resolution 800 x 600) was mounted on the dashboard to the right of the steering wheel, where IVIS are usually installed. The screen was positioned approximately 85 cm far from the driver's head: the brightness and colors of the display were tuned in order to highlight the contrast between the background and graphic elements of the secondary task (see 2.3.4).

2.3. Procedure

2.3.1. Information to participants

All participants were provided with a brief explanation about the LCT and were informed about the purpose of the experiment, its procedure, equipment and expected duration. We gave them the chance to give up the experiment at any time without any consequences. All participants gave explicit consent about all data recording and analysis.

2.3.2. Training

Three training sessions were performed before conducting the experimental trials. Participants were first trained on the only driving task for at least 2 min, and then trained on the IVIS task alone (1 min minimum). Finally, dual-task training (driving and IVIS concurrently) was performed (2 min at least) to ensure the complete understanding of the tasks to be performed.

2.3.3. Primary task: lane change test (LCT)

In the LCT the subjects were required to perform at least 18 lane changes on a 3 km straight three-lane road. Road signs, appearing every 150 m on both sides of the road (Fig. 2), indicate Lane changes; vehicle's speed, controlled by the simulation software, was kept at 60 km/h. The main purpose of this kind of test concerns the quantitative assessment of driving primary task performance degradation while a concurrent secondary task is performed. Participants were instructed to perform good lane keeping when driving straight and to begin lane changing as soon as they could see the signs, but not before. No instructions were provided about how to prioritize attention between the driving task and the secondary task. Participants were explicitly required to perform the dual task condition to the best of their capability (ISO/DIS 26022, 2007). It was particularly emphasized that the goal of the test was not at all to evaluate the participants' driving skills, but exclusively to estimate the negative effects that in-vehicle multitasking may have on driving performance.

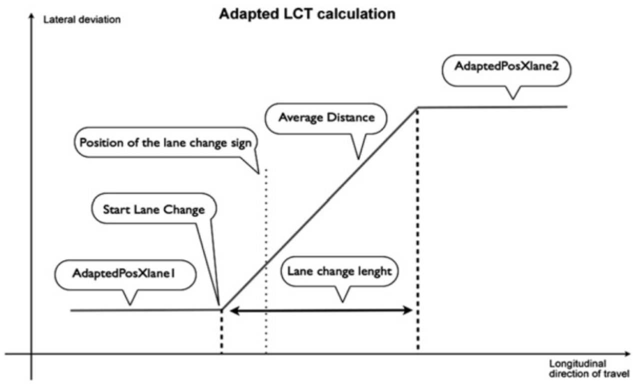

Fig. 2. Adapted LCT performance indicator. Solid line : *adapted* lane change curve.

2.3.4. Secondary task: IVIS

We chose the Surrogate Reference Task (SuRT; Mattes, 2003) since we did not aim at the assessment of a specific commercial IVIS system. Nonetheless, we had to ensure that the secondary task would request - like most actual IVIS systems - both visual perception and manual response.When such activities need to be time-shared, the occurrence of a loss of performance is more likely (Wickens, 2002). Carsten et al. (2005) suggest three criteria for choosing IVIS surrogate secondary task:

- They should have well defined modality (auditory or visual or their combination).
- The distinction between cognitive and visual tasks should be clear.
- Task difficulty should be manipulable.

Young and Regan (2007) point out that most artificial tasks, which are used in experimental research - like arithmetic calculation, mental rotation, etc. - may lead to a dual-task effect overestimation. Support for the choice of the SuRTwas further provided by Wynn and Richardson (2008), suggesting that the SuRT-induced workload may reflect the one of a real task. However, it should be mentioned that real-world IVISs could lead to an unpredictable and time-lasting combination of task loads (visual, cognitive, and manual), which is hard to model in laboratory settings (Carsten and Brookhius, 2005). A two-column SuRT was set up: participants were required to double-click on the portion (left or right) of the screen where the target circle was located. Two difficulty levels were used: an easy one with fewer distractors (small circles), and a difficult one with more distractors. In both difficulty levels, targets (large circles) had a diameter of 1.4 cm (distractors 0.7 cm).

2.4. Experimental design

A within-subjects design was used: two single-task runs were collected, one at the beginning (A = baseline) and one at the end (F = control). Four dual-task runs (B, C, D, E) were performed between the single-task runs, two with an easy SuRT and two with a difficult one

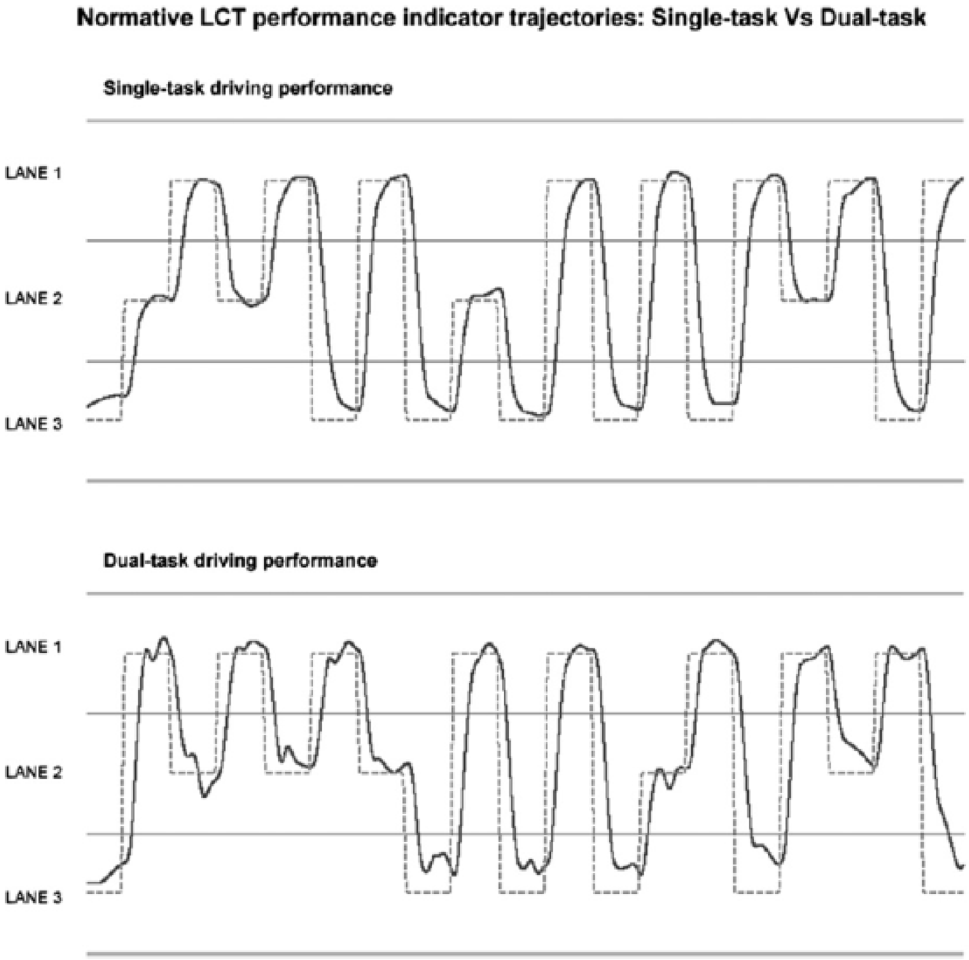

Fig. 3. Comparison between the normative curve (dashed line) and the driver course (solid line) trajectories in the single-task versus dual-task condition.

(see Section 2.3), in random order. Six different driving scenarios were set up, each one having 18 lane change signs: the scenarios differed for the order and type of sign presented. All participants performed all six scenarios, in random order. Each scenario had a length of 3500 m: during the first 500 m participants were asked to start the engine and reach the speed of 60 km/h. Once the vehicle reached a 60 km/h speed the driving simulator software automatically limited the speed at this threshold. When the 500th meter was reached, a START sign appeared on the left and right sides of the road, indicating that the LCT was to be performed. An END sign at the end of the track indicated that the task was completed (ISO/DIS 26022, 2007).

3. Results

A repeated measure ANOVA on the dependent variables was used with a Greenhousee-Geisser correction.

3.1. Normative LCT performance indicator

A repeated measures ANOVA was conducted on the Normative LCT performance indicator revealing no significant general effect across the experimental trials [A, B, C, D, E, F]. This result confirms the outcomes of previous LCT simulator studies. Wynn and Richardson (2008) recorded the deviation of the drivers' course from a unique normative curve in seven conditions (including three difficulty levels of the SURT task). No relevant differences were found among the conditions, even if these differences were clearly perceived by drivers as seen from the NASA-TLX self-reporting questionnaire (Benedetto et al., 2011). Better results were obtained by Harbluk et al. (2009), since this indicator was able to discriminate between drivers' performances in the single and dual task, but not among the dual-task conditions (i.e. drivers' interaction with three different navigation systems). Even though this indicator has been recognized as practical and with the potential to distinguish drivers' performance patterns under different dual-task conditions (Burns et al., 2006), there is limited research on the method concerning the sensitivity of the average deviation from the normative curve (Burns et al., 2006) and it has been considered too theoretical (Rognin et al., 2007) since it does not consider the individual differences among drivers in the driving course.

3.2. Adapted LCT performance indicator

Repeated measures ANOVA on the Adapted LCT performance indicator returned a significant general effect ($F(5,75) = 14.8$ $p < .01$) across the experimental trials [A, B, C, D, E, F]. Since planned contrasts revealed no significant differences within the dual-task conditions [B, C, D, E], these values were averaged. Repeated measures ANOVA were carried out revealing significant general effect ($F(2,30) = 6.45$ $p < .01$) across the experimental trials (baseline = [A], dual-task = [B, C, D, E], control = [F]). Planned contrast between baseline and dual-task revealed a significant effect ($F(1,15) = 22.36$ $p < .01$). Also between control and dual-task a significant effect has been revealed ($F(1,15) = 54.49$ $p < .01$). This is consistent with the results of previous works (Bruyas et al., 2008; Tattegrain-Veste and Bruyas, 2006). Bruyas et al. (2008) performed a sensitivity analysis of the indicator by comparing the mean course deviations to the adapted curve of fifteenth drivers in the single and dual tasks (auditory and visual). The comparison revealed a significant difference of the indicator according to the tasks, higher in the dual-task condition (i.e. lateral control impairment) like in the present study. Planned contrast showed no effect between baseline and control: the Adapted LCT performance indicator returned a mean area of 497.86 (SD = 95.85) m^2 in the baseline, 468.13 (SD = 76.28) m^2 in the control condition. A repeated measures ANOVA on the Adapted LCT performance indicator was carried out revealing significant general effect ($F(5,75) = 14.51$ $p < .01$) across the experimental conditions [baseline, easy SuRT (dual-task 1st run), easy SuRT (dual-task 2nd run), difficult SuRT (dual-task 1st run), difficult SuRT (dual-task 2nd run), control]. Since no differences were found within the easy SuRT (dual-task 1st run and dual-task 2nd run) and difficult SuRT (dual-task 1st run and dual-task 2nd run) trials, these conditions were grouped in 2 categories called easy and difficult by averaging values. Planned contrast between baseline and easy revealed a significant effect ($F(1,15) = 17.33$ $p < .01$). Between control and easy planned contrast revealed a significant effect ($F(1,15) = 38.70$ $p < .01$). Planned contrast between baseline and difficult revealed a significant effect ($F(1,15) = 24.19$ $p < .01$). Between control and difficult planned contrast revealed a significant effect ($F(1,15) = 58.13$ $p < .01$). The comparisons between single task and the two difficulty levels of secondary task were consistent with the studies conducted by (Bruyas et al., 2008; Tattegrain-Veste and Bruyas, 2006).

A step beyond was reached in the comparison between performances in the easy and difficult conditions. In a previous experiment (Bruyas et al., 2008), authors tried to figure out significant differences between driving performances during the execution of two secondary tasks (both auditory and visual, including SuRT) with different levels of perceived difficulty (measured by means of a subjective rate scale). None of the performance measures, including the Adapted LCT performance indicator, were able to discriminate among the tasks. In this study, however, planned contrast between easy and difficult categories revealed a significant effect ($F(1,15) = 7.81$ $p < .05$). Mean area in the easy and difficult trials was, respectively, 622.38 (SD = 111.12) m^2 and 671.22 (SD = 123.1) m^2 (Fig. 4).

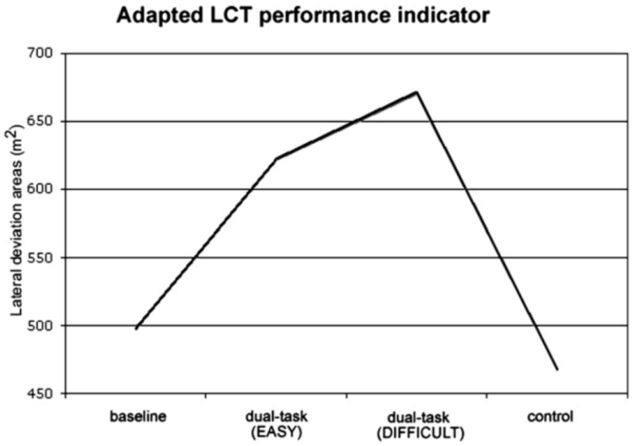

Fig. 4. Lateral deviation areas of the Adapted LCT performance indicator in the four driving conditions.

3.3. High Frequency Component of steering angle (HFC)

Repeated measures ANOVA were carried out on HFC revealing significant general effect ($F(5,75) = 5.56$ $p < .01$) across the experimental trials [A, B, C, D, E, F]. Since planned contrasts did not show significant differences within the dual-task conditions [B, C, D, E] and the dual-task SuRT conditions (easy and difficult), these values were averaged. Repeated measures ANOVA were also conducted revealing significant general effect ($F(2,30) = 6.45$ $p < .01$) across the experimental trials (baseline = [A], dual-task = [B, C, D, E], control = [F]). The planned contrast on HFC between baseline and control was significant ($F(1,15) = 4.73$ $p < .05$) even if the average value of this indicator in the latter (HFCcontrol = 0.67) was higher than in the former (HFCbaseline = 0.63), thus revealing a deterioration in the lateral control of the vehicle due to an increased number of steering corrections. The opposite was expected as a consequence of an increased experience in the driving task and a higher confidence with the simulator. The contrast baseline versus dual-task ($F(1,15) = 10.49$ $p < .01$) revealed that HFC significantly increases in the dual-task conditions; this confirms that steering frequency due to lateral corrections increases with increasing workload (Antin et al., 1990; MacDonald and Hoffman, 1980; Verwey, 1991).These outcomes are also confirmed by Verwey (2000) who found that steering frequency increases significantly in a visual research and motor task, if compared with a single driving condition or dual-task with auditory interaction. Even if the comparison between baseline and dual task met the expectations, this result was not confirmed by the comparison between control and dual-task that revealed no significant effect and an increment of the HFC value in the former. Since in any case from the baseline to the control we observed a deterioration of participants' performances, a possible effect of a higher value of HFC in the control condition can be associated to participants' stress and fatigue (Krajewski et al., 2009).

4. Discussion

The purpose of the study was to compare the capabilities of three different driving performance indicators in discriminating drivers' behavior in the LCT.

The Adapted LCT performance indicator revealed to be the most powerful indicator among the three, discriminating between the single-task conditions (baseline, control) and the dual-task (B, C, D, E) ones, and between the single-task conditions (baseline, control) and the dual-task ones while an easy and a difficult SuRT task were performed. The strength of this indicator lies in its ability to reflect individual practices in terms of lane change initiation and performance, then keeping the "driving style" as a constant in the evaluation of the deviation from the optimal curve and not as an element of the deviation. The Adapted LCT performance indicator looks definitely stronger if we consider its ability to reveal small differences within similar IVIS interfaces. Additionally two other advantages should be taken into account. Firstly, it allows researchers to make experimental evaluations within a restricted number of participants, since its computation somehow includes each single person's driving style. This would not be possible with the Normative LCT performance indicator, given the need to increase the sample size (or the number of lane changes) to flatten the driving performance perturbations due to different driving behaviors. Secondly, the performance values computed with the Adapted LCT performance indicator are "driver tailored" and can be directly compared across participants, with no further standardization required.

The Normative LCT performance indicator did not succeed in predicting the level of visual workload by measuring performance degradation on the primary task; as stated in previous studies it is considered too theoretical (Rognin et al., 2007), especially when it is applied to a small sample of drivers with heterogeneous characteristics. For this reason, we expect higher benefits from this indicator in detecting relevant visual workload variations between dual and single tasks if most of the factors that can induce variations from the normative model are controlled: for instance participants' age, driving experience, familiarity with the driving simulator and IVIS. At the same time, benefits are expected after long driving sessions: as soon as the driver becomes confident with the driving environment, the effects of the above mentioned factors are significantly reduced. In the experiment conducted by Wilschut et al. (2008) twelve female drivers in the age between 20 to 22 years old and with a 2 year driving experience were asked to perform the LCT task. Before starting the experiment they were asked to repeat a trial until they reached a level of performance revealing their confidence with the simulator and the driving task. Thanks to these requirements the authors were able to detect significant differences in driving performances between two dual-task conditions and between single and dual task.

The HFC indicator has been largely used for monitoring the effect of visual distraction on the primary tasks, providing good results in classifying different visual workload profiles. According to our results, the HFC revealed rather good performances in discriminating between single (baseline) and dual task. However, no differences were found between control (single task) and the dual-task conditions, suggesting that the high performance degradation observed at the end of the experiment (control), was probably due to fatigue or stress effects. In light of that, there are two possible interpretations of our results. Firstly, HFC is usually applied to driving experiments where the geometry of the driving path does not influence steering movements and reversal rate (i.e. straight road with small radius curves). However, the filter applied to the steering signal is able to limit the effect of steering turnings associated to the lane change manoeuvres. Secondly, according to Jex et al. (1966) the human bandwidth in tracking tasks ranges from 0.6 Hz (i.e. the cutoff frequency we adopt for the configuration of the HFC filter), to 2 Hz, supporting that 0.6 Hz is a too small upper limit. It should thus be considered to filter the steering signal at 2 Hz instead of the 0.6 Hz used in this work.

5. Conclusions

From an implementation perspective, benefits in terms of both efficacy and efficiency can be achieved with the Adapted LCT performance indicator. This indicator revealed itself to be able in discriminating even small interface changes on an IVIS. Thus designers could gain further support when choosing interface configurations - in the early stages of design - with respect to the visual workload that could be generated using a small set of inputs (vehicle position, lane width, lane change sign content and position). When choosing the secondary task, besides visual tasks, cognitive tasks should be considered as well, since they have further detrimental effects on driver' s performance, especially on longitudinal vehicle control (Carsten and Brookhius, 2005). Future work will firstly concern the evaluation of the Adapted LCT performance indicator in high complexity visual task, increasing for example the difficulty of the SuRT by lowering the diameter of the target circles, thus making them more similar to the distractors and, as a consequence, harder to detect. Secondly, getting out of visual tasks, would be interesting to test the power of the Adapted LCT performance indicator in more naturalistic tasks such as phone calls, conversation with passengers, vocal interaction.

Acknowledgments

We would like to thank Marco Scavarda for the development of the software application for Lane Change Test analysis and Lorenzo Bruschetti for the work conducted in the review of literature studies concerning lateral driving behavior.

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