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ANALOGUE VERSUS DIGITAL SPEEDOMETER: EFFECTS ON DISTRACTION AND USABILITY FOR TRUCK DRIVING

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ABSTRACT: The instrument cluster in the trucks become screens and this brings new challenges for the speedometer design. Both traditional speedometers (i.e. analogue and digital) present design advantages. However, the existing human-factors literature does not allow concluding whether one or the other type is more usable and less distracting. Digital speedometers would be more appropriate for absolute and relative reading, while analogue speedometers would be more efficient and less distracting for detecting dynamic speed change. This study compared both speedometer types on a screen instrument cluster in simulated truck driving. The task-dependant results were replicated. This study updates previous literature and provides a basis to investigate other speedometer types which would be efficient on the three tasks.

1 INTRODUCTION

During driving, drivers interact with the speedometer in a monitoring way for different purposes: maintain vehicle speed within desired safety margins, follow speed limit signs, carry out necessary adjustments (acceleration or deceleration), in overtaking situations, or in any driving environment in which speed plays a major role. Speedometer design has critical implications for road safety. Speedometer frequency of usage is high and the off-road glances associated could overlap with a time critical event [1]. Recarte and Nunes (2002) stressed that speedometer visual inspection increases in a restricted-speed road environment [2]. Truck drivers spend much time on the road in a professional context (up to 56h in any given work week) [3], and speed has become a particular concern for them due to the strengthening of the regulation and road controls. Moreover, even if trucks drivers are experts, human error accounts for 90% of trucks accidents [4]. A misjudgement of speed can lead to rollover in a bend (particularly for concrete mixer trucks), jackknifing at braking, or swinging out on slippery roads [4]. For those reasons, it is essential to carry out the speedometer design with the following objectives: provide accurate speed information in a quick way (i.e. minimize eyes off-road time), and avoid unnecessary mental workload increase (i.e. information easy to understand and interpret).

Two main speedometers types are currently proposed in the truck industry: analogue (i.e. moving indicator along a scale) and digital speedometers (i.e. digits). In the human factors literature, some studies investigated the effects of both speedometers on human behaviour. Results are not clear and it seems that the more appropriate mean of presenting the speed information to the driver depends on the task performed. A digital speedometer would be more appropriate for an absolute reading of the speed value [5–8], and for a relative reading task (i.e. compare to a target speed) [5, 9], while an analogue speedometer would be better for reading a dynamic speed change [9–11].

However, updating these studies could be beneficial for trucks' HMI designers. Indeed, most studies are dated and have been conducted on cars. Compared to car driving, truck drivers' eye position is higher and farther from the dashboard. Differences in terms of vehicle speed variation (due to vehicle weight) and criticality could impact speed management and control. We also can assume different results due to social changes (i.e. different relation to speed), technology changes (i.e. the expansion of digital formats in the everyday life), and speedometer context of use (e.g. drivers need now accuracy when choosing a cruise control target speed). Moreover, existing studies have been obtained with conventional mechanical and physical supports. Advancements in display technologies with screens as instrument clusters make it interesting to update the results for a contemporary and realistic view.

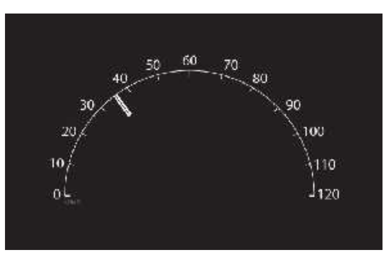
The objective of this study is to compare an analogue and a digital speedometer in simulated truck driving in terms of usability and distraction. As mentioned above, the literature indicates that both displays present benefits depending on the task tested. This study aims to confirm if those results are applicable on screen instrument cluster for truck driving.

2 PARTICIPANTS

18 men trucks drivers (42 years±7.2) took part in the experiment. Most participants drove a truck several times a month (33% less than once a month). All participants held valid truck licences and reported normal or corrected-to-normal vision and audition. In their cars, 55% of the participants used an analogue speedometer (39% use a digital one). For truck driving, most participants drove with a digital speedometer (94%, all in Renault Trucks). Written informed consents from each participants were obtained.

3 MATERIALS

The analogue speedometer was composed of a semi-circular fixed scale graduated inside and marked outside all 10 km/h between 0 and 120 km/h (Fig. 1a). The moving pointer was a non-complete needle pointing the scale attached to the scale. The digital speedometer was a 2 digits display with a refresh rate of 1.25Hz (Fig. 1b). Both speedometers were centred in upper half of an 8” screen in place of the instrument cluster. Decision on the graphic characteristics of the two speedometers have been taken considering existing fully reconfigurable clusters in cars (e.g. the needle is often cut off to display something inside), and the existing human factors knowledge (e.g. scale marked in numbers multiples of 10) [7].

a. 

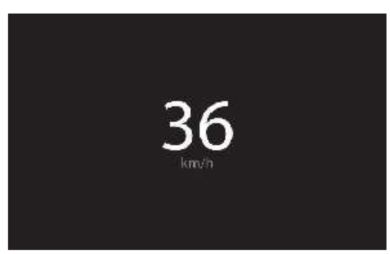
b. 

Figure 1. Representation of the two speedometer displays.
a. Analogue speedometer;
b. Digital speedometer

Three tasks were asked to participants. For the task 1, drivers were required to report the speed (e.g. speed value displayed: 49; answer: '49'). For the task 2, drivers were asked to say if the speed value displayed is under or over 50 km/h (e.g. speed value displayed: 49; answer: 'minus'). For the task 3, drivers were asked to say if the speed displayed was increasing or decreasing (e.g. speed displayed: from 30 to 49 km/h; answer: 'acceleration'). 12 stimuli were presented for each speedometer type and for each task.

4 PROCEDURE

Before the experimental phase, participants were informed of the details of the study and signed a consent form. Afterwards, the head-mounted eye tracking device was positioned and calibrated (monocular Ergoneers Dikablis Essential, 50Hz). Participants were given a 5 min familiarisation with both speedometers displays. Before each session, participants read the instructions and performed 4 training trials (to ensure the comprehension of the task).

During the experiment, participants drove on a fixed-base medium-fidelity truck driving simulator. They were required to follow a red car on a highway. The information cluster remained black most of the time. Every 8 to 12s (randomly) a sound announced that the speedometer was about to be displayed. Thus the driver could give his answer aloud (that would remove the display). The test was composed of 6 sessions, corresponding to the 3 tasks for the 2 speedometers displays. A cognitive distraction questionnaire was proposed after each driving session.

At the end of the study, participants were asked to report their preferences (order of preference and satisfaction score). Each participant was tested individually and experienced all conditions. The order of the experimental condition presentation were counterbalanced following three Latin squares, and stimuli presentation was randomly arranged for each session. The total test duration was about an hour and a half.

5 RESULTS AND DISCUSSION

Cognitive distraction was self-reported thank to the Rating Scale Mental Effort [12]. Scores between 0 and 150 were acquired after each session in order to evaluate the effects of the speedometer and the task. Scores were analysed using non-parametric Friedman and Wilcoxon tests for paired samples. Visual distraction was analysed through the total glance time away from road (from stimulus display to stimulus disappearance). 2×3 repeated-measures ANOVAs and Tukey HSD post-hoc tests were performed on corrected means. Values apart from the mean value minus or plus two standard deviations were discarded from the data analysis. Regarding usability measures, efficiency was assessed through task completion times (from stimulus display to driver's answer) and accuracy (driver's answer with the real value displayed). After the three driving sessions with one speedometer type, global usability was examined through a five items questionnaire (5 points Likert scales) corresponding to the five aspects of usability defined by Nielsen (i.e. learnability, efficiency, memorability, errors and satisfaction)[13]. Finally, driver preference was acquired at the end of the experiment (order of preference and satisfaction score between 0 and 10). 2×3 repeated-measures ANOVAs and Tukey HSD post-hoc tests were performed on task completion times. Friedman and Wilcoxon tests were computed on accuracy, usability and satisfaction scores.

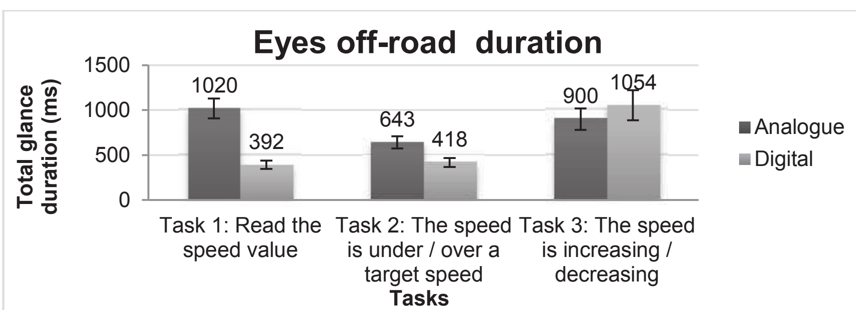


Figure 2. Total off-road glance duration in milliseconds (with standard deviation) for the two speedometers (analogue and digital) on the three tasks of the experiment.

For reading the speed value (task 1), clear advantages were found for the digital speedometer. The reported cognitive effort was lower with the digital than with the analogue speedometer (13.5 against 34.4; Z=3.574, p<0.001). The visual distraction (Fig. 2) was also lower with the digital speedometer (total glance time away from road of 392ms against 1020ms with the analogue speedometer; $p<.001$), and the task completion times followed the same pattern (920ms against 1494ms, $p<.001$). The accuracy for the analogue speedometer was quite good (average error less than 1 km/h), but no errors were made with the digital speedometer ($p<.001$).

To tell if the speed value is under or over 50km/h (task 2), the digital speedometer was also better. Total glance duration on the speedometer and task completion times were lower with the digital speedometer than with the analogue speedometer (total glance duration: 418ms against 643ms, $p<.001$; task completion times: 1038ms against 1146ms, $p<.001$). No significant difference was found regarding accuracy and cognitive distraction (18.9 for the digital and 22.2 for the analogue, $p=.334$).

On the contrary, to tell if the speed is decreasing or increasing (task 3), the analogue speedometer was more appropriate. Away from road glances were reduced by about 155ms (900ms against 1054ms, $p<.001$), and task completion by about 410ms (1397ms against 1804ms, $p<.001$).

Regarding usability, both speedometers were perceived as usable by drivers and every dimension's scores were good. Only the propensity to error was perceived differently. Drivers reported that they feel they can make more errors with the analogue speedometer (3.68 against 4.83, $Z=3.180$, $p<.001$). Global preference goes to the digital speedometer: 13 drivers on 18 preferred the digital speedometer. Drivers scored better the digital (8.17) than the analogue speedometer (6.78, $Z=2.792$, $p<.001$).

These results, dependent of the task performed, are completely in line with the previous literature [5–11]. The differences between both speedometers are even more pronounced in this study (e.g. digital speedometer minimizing eyes-off-road time from 628ms against 70ms in the study of Ishii, 1980)[8]. The usability and satisfaction results meet conclusions from studies conducted with car drivers [2]. However, the preference for digital over analogue displays may reflect their familiarity with these displays. Indeed, most of participants report using a digital speedometer in the trucks they use to drive. It is interesting to note that 2 drivers quoted differently the grade and the ranking (i.e. give a better score to digital but rank analogue first). They reported that they find digital more usable but prefer having an analogue speedometer for aesthetic reasons.

Globally, the digital speedometer seems to be a good trade-off on the three tasks. Despite the fact that an analogue speedometer would save 155ms of eye off-road time to judge a speed change, the gains in term of visual distraction for the task 1 and 2 (respectively 628ms and 225ms) are significantly more consistent. For the speed reading task, the gain of almost 700ms represents a distance of 16m at 90km/h with the eyes on road.

6 CONCLUSION

This experiment compared an analogue and a digital speedometer in terms of usability and distraction in simulated truck's driving. The results existing in the literature for cars on mechanical instrument clusters have been replicated and extended to truck drivers on a screen instrument cluster. Future research can build on these results to investigate new speedometer representations that would be more efficient for the three reading types. For example, it would be interesting to evaluate if redundant speedometer (i.e. combination of analogue and digital speedometers) could couple the gains of both types presented isolately.

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