Gauges design for a digital instrument cluster: Efficiency, visual capture, and satisfaction assessment for truck driving

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Taxonomy	Cognitive Ergonomics, Display-Control Relationship, Control Design, Design Control
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Highlights

- Different gauge designs are best for different reading tasks
- Horizontal gauges and pointer indicator are more efficient and less visually demanding
- Circular and horizontal gauges are preferred by truck drivers
- For quantitative reading, eyes on-gauge time can be decreased by 280ms by changing the design of a gauge

Gauges design for a digital instrument cluster: efficiency, visual capture, and satisfaction assessment for truck driving.

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Running head

Comparison of different gauge designs.

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Abstract

This study aims at increasing knowledge on the best way to design trucks' gauges on digital instrument clusters. Trucks are equipped with many gauges that the driver has to monitor while driving. Digital instrument clusters offer new design possibilities and the human factors literature presents only limited answers on safe and efficient gauge designs. Eighteen truck drivers were presented with eight gauges with different shapes, orientation and indicators to perform three reading tasks (quantitative, qualitative and check reading). Results showed that gauge design impacted task completion times, eyes on-gauge duration and satisfaction. Horizontal gauges and pointer indicators were more efficient and less demanding visually. On the subjective side, circular and horizontal gauges were preferred by drivers. Specific gauge designs implied a gain in visual demand up to 250ms. For the design of gauges on digital instrument cluster, information processing can be facilitated thanks to basic design changes.

Keywords

HMI design; Interface evaluation; Display design principles; Commercial vehicles dashboards; visual capture

Précis

Truck dashboards contain many gauges and digital instrument clusters offer new design possibilities. Eight different gauge designs were compared on three reading tasks: quantitative reading, qualitative reading and check reading. Human factors recommendations are provided in order to design gauges in a safe and efficient way.

1 Introduction

Within dashboards, gauges have always been major components. Oil level gauge was the first instrument installed inside vehicles around 1900 before speedometers (Akamatsu, Green & Bengler, 2013). Nowadays, several gauges are displayed in automotive dashboards to monitor vehicle information, and this is especially true for trucks (Figure 1). Compared to cars, trucks' mechanical configuration and high amount of functions imply an increased amount of information to be monitored by the driver (e.g. up to two air pressure circuits, regeneration filters level, fuel additive tank level, etc.). Some truck gauges are monitored at vehicle start (e.g. air pressure gauge), but other gauges can be used while driving even in complex situations (e.g. fuel gauge). Attentional resources are required to monitor the different dynamic gauges. As a result, any improvements in gauge design would potentially translate into safety improvements of the driving task.

Figure 1. Example of 2016 truck dashboard (Mack Trucks North America, Series Granite)

Although literature on gauge design is extensive in related research areas, some knowledge is missing to define truck gauges, especially with the generalization of digital clusters that offers more design flexibility. More generally, we have identified five methodological limitations, preventing us to generalize the results obtained to the specific context of truck gauges. The first concerns the ecological nature of the task proposed. For instance, some of the results available in the literature have been obtained using the tachistoscopic method

with controlled exposure time (e.g. 120ms in Sleight, 1948), which would affect results and be too far from what occurs in practice (Grether, 1949). The second concerns the lack of a systematic examination of each attribute on each reading type. Indeed, studies often compared few gauge attributes of very different designs, what does not allow judging the weight of each attribute and the interaction between them (Sleight, 1948). Thus, it is of particular interest to investigate how different gauge attributes impact on human monitoring. The third is the specificity of the task proposed in that most of the experiments carried out on the topic exclusively focus on the quantitative reading task (i.e. reading a number). In real life conditions, gauge monitoring implies not only quantitative reading (e.g. exact speed), but also other monitoring tasks, clearly identified in the Human Factors literature: quantitative reading, qualitative reading, and check reading (Endsley, 1988; Sanders and McCormick, 1993). 'Quantitative reading' is the processing of a precise numeric value (e.g. the engine speed value). 'Qualitative reading' is used to obtain a trend or change in direction (e.g. the quarter of the fuel level). 'Check reading' determines if a value is within a normal range or not (e.g. engine cooling temperature too hot). More data are thus required to assess the impact of gauge design on different reading tasks (i.e. qualitative reading and check reading). The fourth limitation is that some studies analyzed gauge performance with specified nature (e.g. air speed indicator; Grether & Connell, 1948), what makes these results less transferable to other natures or new gauges. Considering "generic" gauges (without nature) would allow attributing results to design changes only, rather on the semantics associated. The fifth is the issue of transferability of results to the truck domain. More particularly, truck drivers' eye distance to the instrument cluster is greater and implies a larger visual angle compared to car driving. Moreover, truck drivers spend much time on the road in a professional context (up to 56h in any given work week; Bedinger et al., 2015). Their expertise and their particular relation to the vehicle could impact their gauge monitoring process. To bypass these five methodological limitations, the present study proposes respectively: (1) to assess gauge reading *during a driving activity*; (2) to examine the effect

of three gauge attributes *in a systematic way*; (3) to present drivers with *three gauge reading tasks*; (4) to present a *generic* gauge to increase the generalization of our results; and (5) to assess *truck drivers*. That being said, the next issue concerns the gauge attributes of interest. Today, gauge design is quite inconsistent across trucks manufacturers. Nevertheless, extensive research has been carried out for cars drivers (Green, 1984; Green, 1988; Mayer & Laux, 1992) and aircraft pilots (Baker & Grether, 1954; Connell, 1950; Grether, 1949; Grether & Connell, 1948). Three main gauge types were investigated on the different reading tasks: counters or numeric displays, fixed pointer with moving scale, and moving pointer with fixed scale (Baker and Grether, 1954). Counters are reported fast and accurate for quantitative reading, but less suitable for qualitative and check reading (Baker & Grether, 1954; Chapanis, 1960; Green, 1988; Grether, 1949; Sanders & Mc Cormick, 1993). Fixed pointer with moving scale gauges would be globally poorly efficient on the three reading tasks compared to other gauge types (Baker & Grether, 1954; Chapanis, 1960; Connell, 1950; Green, 1988; Grether & Connell, 1958). Moving pointer with fixed scale display would be best for qualitative and check reading, and perform well on quantitative reading (Baker & Grether, 1954; Chapanis, 1960; Green, 1984; Green, 1988; Grether, 1949; Grether & Connell, 1958; Sanders & Mc Cormick, 1993). This gauge type is also the main display used in current truck models. Nevertheless, many types of moving pointer with fixed scale exist, with different design attributes such as the marking of the scale, the way of numbering, the shape and orientation of the gauge, or the indicator type. These attributes have been subjects of several experiments and recommendations have been proposed. For instance, color coding would help the understanding and the detection of critical reading (Green, 1984; Mayer & Laux, 1992); numbers for dials can be inside or outside the scale (Kappauf, 1951); scales should be marked in numbers that are even multiples of 10 (Green, 1988); aligning pointers to the normal value when multiple gauges have to be checked close to each other would reduce reading time and errors (Green, 1988; Warrick & Grether, 1948); etc. In sum, previous experiments available in the literature have investigated a large set of

gauges attributes (see Green, 1988 for a meta-analysis) but even more gauges' attributes could be envisioned. All those attributes cannot be manipulated experimentally in a single study. Thus, in this reported experiment the choice has been made to focus only on three major gauge attributes: shape, orientation and indicator.

In the past, those three gauges attributes have been reported to impact reading performance. In an early study in which participants were asked to perform quantitative reading (e.g. read an exact value on a scale), accuracy of reading the gauges were ranked as follows: open-window, circular, semi-circular, horizontal linear and vertical linear (Sleight, 1948). During brief presentation of gauges (10 sec films), the number of quantitative reading errors was found much higher for vertical linear gauges as compared to both horizontal linear and circular gauges (Graham, 1956). Circular gauges were also found more effective than vertical linear gauges when assessing the number of correct quantitative readings over five experimental sessions (Carveth & Adams, 1964). Grether and Connell (1948, in Murrell, 1965, p.162) have suggested that vertical linear gauges are more effective than circular gauges because an upward movement of the pointer is always associated to an increase in value. The design of pointers has also been under the scope of investigation, but the design of a physical pointer itself only has a small effect on performances (see Green, 1988 for a review). Regarding the shape, orientation and indicator of gauges on preferences, previous research reported that circular gauges might be preferred to linear gauges (Carveth & Adams, 1964; Graham, 1956; Green, 1988; Sleight, 1948), horizontal gauges to vertical gauges (Graham, 1956; Murrell, 1965; Sleight, 1948), and pointers to bargraphs (Mayer & Laux, 1992).

As in-vehicle interfaces design may impact the driver's ability to perform the primary driving task while monitoring the cluster, it is essential to deliver to practitioners clear and directly applicable design requirements (François, Osiurak, Fort, Crave & Navarro, 2016). This study addressed the following research questions:

- Does gauge design impact efficiency, on-gauge glance duration and satisfaction?

- What attributes really matter in gauge definition and do they interact?
- Which kinds of gauge displays are best for specific reading tasks?

Eight gauges were designed based on a factorial experimental design with three attributes: shape (circular or linear), orientation (horizontal or vertical), and indicator (pointer or bargraph). They were assessed on quantitative, qualitative, and check reading.

2 Material and methods

2.1 Participants

Eighteen trucks drivers took part in this experiment (all men, mean age: 43 years, SD: 5.3). All participants held valid truck licenses for 13 years on average (SD: 8.6). Most participants drove a truck several times a month (78%). All reported normal or corrected-to-normal vision and audition. Written informed consent was obtained from each participant.

2.2 Equipment

The fixed-base medium-fidelity driving simulator was composed of a truck seat, two thirds of a real dashboard, and a 65 inches plasma screen using Oktal SCANeR™ for traffic scenario and truck model. Throttle pedal, brake pedal, and steering wheel were original parts of a Renault Trucks T. A highway environment was used, with a random traffic around the vehicle. A 15.4 inches screen was located in place of the instrument cluster behind the steering wheel to display stimuli (height: 332mm, width: 207mm, resolution: 1280x800, refresh rate: 60Hz). A binocular head-mounted eye tracker was used to capture the eye gaze (Tobii Glasses 2; scene camera resolution: 1920x1080; eye camera tracking frequency: 50Hz). Gaze raw data were filtered using the Tobii I-VT fixation filter configured so that short fixations were not discarded (Olsen, 2012).

2.3 Material

Gauges. Eight gauges representations (Figure 2) were presented centered in upper half of the screen. Gauges were generic (non-associated to a function, e.g. fuel level) for generalizability reasons. They were presented without scale units. Scales were monochromes, divided in 4 parts with internal graduations (block types), with the last half part in red to indicate a warning zone (always at the end of the gauge, such as for a temperature gauge type). A zero marker indicated the reading direction of the gauge. Three gauges attributes were presented and fully mixed resulting in eight gauge representations:

- Shape: Circular (demi circular gauge; diameter: 40mm) or Linear (length: 62.8mm)
- Indicator: Pointer (length: 20mm/16mm) or Bargraph (white filling of the scale)
- Orientation: Horizontal or Vertical (90° anti-clockwise rotation)

Figure 2. Gauge representations from Gauge 1 to Gauge 8. Each gauge is defined by its shape (C: Circular or L: Linear), its indicator (P: Pointer or B: Bargraph) and its orientation (H: Horizontal or V: Vertical).

Tasks performed. Participants were required to perform a primary driving task, which was to follow a red car on a highway. Moreover, each gauge was tested on three reading tasks:

- Task 1 (quantitative reading): 'What is the gauge value between 0 and 100?' (answer: a number between 0 and 100)

- Task 2 (qualitative reading): ‘In which quarter is the gauge value?’ (answer: one, two, three or four)
- Task 3 (check reading): ‘Is the gauge value in the red zone or not?’ (answer: yes or no)

For the tasks 1 and 2, four stimuli were presented for each gauge (1 with the value randomly chosen between 5 and 24; 1 between 25 and 49; 1 between 50 and 74; and 1 between 75 and 95). For the task 3, four stimuli were presented for each gauge (1 with the value randomly chosen between 8 and 47; 1 between 48 and 87; and 2 between 88 and 95).

2.4 Procedure

Before the experimental phase, participants were informed of the details of the study and completed a consent form. Afterwards, the eye tracking device was positioned and calibrated. For each test drive, participants were required to follow a red car on a highway. The question drivers had to answer was stated by the experimenter before departure. The information cluster remained black most of the time. Every 6 to 8s (randomly) a sound announced that a gauge was about to be displayed. Thus the driver could give his answer aloud (that would remove the display). The experiment was composed of three test drives (a drive per reading task), all eight gauges designs were randomly presented in each drive four times. At the end of each test drive, participants were asked to rank the eight gauges by order of preference. This resulted in a gauge ranking per reading task. Each participant was tested individually and experienced all conditions. The order of the test drives was counterbalanced following Latin squares. The total test duration was approximately 1h.

2.5 Data acquisition and analysis

Efficiency was assessed through task completion times (i.e. time in millisecond between the display of a gauge and the answer of the participant) and accuracy scores (i.e. task 1:

absolute distance between driver's answer and the real value displayed; task 2 and 3: error rate). Visual capture was analyzed through the total on-gauge glance duration from gauge display to the start of driver's aloud answer. Finally, driver satisfaction was assessed by gauge ranking in terms of preference (from 1 to 8, 1 being the preferred gauge for each of the three reading tasks).

The results are reported dependent variable by dependent variable (i.e. efficiency, visual capture and satisfaction) with the same rationale. First, analyses were computed on gauge attributes (i.e. shape, indicator, and orientation) for the three tasks (i.e. quantitative, qualitative and check reading) to analyze global differences (regardless of the task). Second, for each task, a three-way repeated measures ANOVA was performed on the task completion times and total on-gauge glance duration (within-subject factors manipulated: shape with two modalities: circular and linear; indicator with two modalities: pointer and bargraph; and orientation with two modalities: horizontal and vertical). Tukey HSD tests were used as post-hoc analyses.

Regarding satisfaction ranking analyses, non-parametric Wilcoxon tests for paired samples and Friedman tests were performed. In addition, a hierarchical cluster analysis was also conducted on satisfaction scores (Ward's method applied to Euclidean distances).

3 Results

3.1 Efficiency

Global analysis. Task completion times (Figure 3) and accuracy scores were collected. A significant main effect of the task was found ($F(2,34) = 95.44, p < .001$), post-hoc analyses showed that task 1 (2058ms) implied longer task completion times than task 2 (1232ms, $p < .001$) and 3 (1128ms, $p < .001$).

The effect of orientation was also significant: tasks were performed slower with vertical gauges (1503ms) than with horizontal gauges (1442ms; $F(1,17) = 12.20, p < .01$). Similarly,

tasks were performed slower with bargraph indicators (1498ms) than with pointers (1447ms; $F(1,17) = 8.334, p < .01$). The three-way interaction shape*orientation*indicator was significant ($F(1,17) = 13.84, p < .01$) revealing that gauge 5-LPH (1401ms) was significantly more efficient than four other gauges (gauge 4-CBV: 1551ms, $p < .001$; gauge 6-LBH: 1495ms, $p < .001$; gauge 7-LPV: 1512ms, $p < .01$; gauge 8-LBV: 1490ms, $p < .03$). On the contrary, Gauge 4-CBV was found less efficient than four other gauges (gauge 1-CPH: 1551ms, $p < .001$; gauge 2-CBH: 1495ms, $p < .001$; gauge 3-CPV: 1512ms, $p < .01$; gauge 5-LPH). Gauge 7-LPV was significantly less efficient than gauge 5-LPH and gauge 1-CPH (1418ms, $p < .02$).

Figure 3. a. Task completion times in milliseconds ($\pm$ standard deviation) for the gauge attributes on the three tasks.
b. Task completion times in milliseconds ($\pm$ standard deviation) for the eight gauges on the three tasks.

Task by task analyses. For the **task 1** (quantitative reading), tasks completion times were lower with horizontal (1987ms) than with vertical gauges (2128ms; $F(1,17) = 11.45, p<.01$). The three-way interaction was significant ($F(1,17) = 7.44, p<.02$), and Tukey HSD post-hoc test showed that Task 1 was completed significantly faster with Gauge 1-CPH (1940ms, $p<.001$), Gauge 2-CBH (1922ms, $p<.001$) and Gauge 5-LPH (1980ms, $p<.01$) than with Gauge 7-LPV (2232ms). Reading accuracy was very good with about 2.5% of errors around the real value on the average and not significantly different between gauge attributes.

For the **task 2** (qualitative reading), tasks completion times were lower with linear (1208ms) than with circular gauges (1255ms; $F(1,17) = 8.19, p<.02$). Horizontal gauges (1215ms) were slightly more efficient than vertical gauges (1248ms; $F(1,17) = 11.62, p<.01$). Similarly, pointers (1201ms) were slightly more efficient than bargraph indicators (1262ms; $F(1,17) = 8.39, p<.01$). Accuracy was very good, with less than 2% of incorrect quarter responses, and not significantly different between gauge attributes. The three-way interaction was significant ($F(1,17) = 5.55, p<.04$), and Tukey HSD post-hoc test reported that task 2 was completed faster with the Gauge 1-CPH (1214ms, $p<.05$), Gauge 3-CPV (1215ms, $p<.05$) and Gauge 5-LPH (1147ms, $p<.05$) than with Gauge 4-CBV (1327ms). Gauge 5-LPH was more efficient than Gauge 2-CBH (1266ms, $p<.04$) and Gauge 4-CBV. The Friedman test reported no significant difference of accuracy between gauge attributes.

For the **task 3** (check reading), tasks were completed faster with pointer gauges (1076ms) than with bargraph gauges (1180ms; $F(1,17) = 21.13, p<.001$). Accuracy was extremely good, with less than 1% of incorrect responses, and not significantly different between gauge attributes.

3.2 Visual capture

Global analyses. Visual capture was assessed through the total on-gauge glance duration (Figure 4). A main effect of the task was found significant ($F(2,34) = 115.12, p<.001$),

showing that task 1(1214ms) implied longer on-gauge glances than task 2 (673ms, $p<.001$) and task 3 (600ms, $p<.001$). Regardless of the task, vertical gauges (860ms) appeared more visually demanding than horizontal gauges (798ms; $F(1,17) = 25.46$, $p<.001$). On-gauge glance durations were also longer with bargraph gauges (863ms) than with pointer indicator gauges (795ms; $F(1,17) = 20.13$, $p<.001$). The three-way interaction shape*orientation*indicator was also significant ($F(1,17) = 9.66$, $p<.01$), and post-hoc test reported that Gauge 5-LPH (731ms) was significantly less visually demanding than four other gauges (Gauge 2-CBH: 840ms, $p<.03$; Gauge 4-CBV: 915ms, $p<.001$; Gauge 7-LPV: 870ms, $p<.01$; and Gauge 8-LBV: 864ms, $p<.01$). On the contrary, Gauge 4-CBV implied longer on-gauge glances than four other gauges (Gauge 1-CPH: $p<.01$; Gauge 3-CPV: $p<.01$; and Gauge 5-LPH).

Figure 4. a. Total on-gauge glance duration in milliseconds ($\pm$ standard deviation) for the gauge attributes on the three tasks.
b. Total on-gauge glance duration in milliseconds ($\pm$ standard deviation) for the eight gauges on the three tasks.

Task by task analyses. For the **task 1** (quantitative reading), the main effect of orientation was significant ($F(1,17) = 11.71, p < .01$) showing that vertical gauges (1277ms) were more visually demanding than horizontal gauges (1151ms). The three-way interaction shape*orientation*indicator was also significant ($F(1,17) = 6.96, p < .02$) showing that Gauge 7-LPV (1382ms) was more visually demanding than Gauge 1-CPH (1112ms, $p < .03$) and Gauge 5-LPH (1084ms, $p < .02$).

For the **task 2** (qualitative reading), main effects of shape, orientation, and indicator factors reached significance. Circular gauges (706ms) were more visually demanding than linear gauges (640ms; $F(1,17) = 19.37, p < .001$). Vertical gauges (698ms) were more visually demanding than horizontal gauges (648ms; $F(1,17) = 27.34, p < .001$). Bargraph gauges (704ms) were more visually demanding than pointer gauges (642ms; $F(1,17) = 15.67, p < .001$). The three-way interaction was significant ($F(1,17) = 8.24, p < .02$), and Tukey HSD post-hoc test reported that task 2 implied longer eyes on-gauge duration with Gauge 4-CBV (769ms) than with five other gauges (Gauge 1-CPH: 675ms, $p < .05$; Gauge 3-CPV: 673ms, $p < .04$; Gauge 5-LPH: 553ms, $p < .001$; Gauge 6-LBH: 658ms, $p < .02$; and Gauge 7-LPV: 665ms, $p < .03$). On the contrary, Gauge 5-LPH was less visually demanding than all other gauges (Gauge 1-CPH: $p < .01$; Gauge 2-CBH: 706ms, $p < .001$; Gauge 3-CPV: $p < .01$; Gauge 4-CBV; Gauge 6-LBH: $p < .02$; Gauge 7-LPV: $p < .02$; and Gauge 8-LBV: 683ms, $p < .01$).

For the **task 3** (check reading), the effect of the indicator was significant: pointer gauges (562ms) were less visually demanding than bargraph gauges (637ms; $F(1,17) = 25.59, p < .001$). The two-way interaction orientation*indicator was also significant ($F(1,17) = 4.75, p < .05$), showing that the effect of the indicator is more pronounced for vertical (vertical-

pointer gauges: 554ms, vertical-bargraph gauges: 654ms; $p<.001$) than for horizontal gauges (horizontal-pointer gauges: 571ms, horizontal-bargraph gauges: 621ms; $p<.04$).

3.3 Satisfaction

Global analyses. Pairwise comparisons were led for each attribute using Wilcoxon tests (Figure 5a). Globally, circular gauges (mean score: 11.17) are preferred to linear gauges (4.10; $Z=3.223$, $p<.001$). Similarly, horizontal gauges (9.04) are preferred to vertical gauges (6.22; $Z=3.462$, $p<.001$).

Figure 5. a. Mean satisfaction scores for the gauge attributes (regardless the task performed)
b. Mean satisfaction score per gauge (regardless the task performed), rectangles represented gauges clusters from the hierarchical cluster analysis.

Task by task analyses. Friedman test reported significant differences between gauges ($\chi^2(7) = 70.70$, $p < .001$). Because very similar satisfaction results were found for the three reading tasks, the analyses are presented together. The effect of the shape was significant (circular or linear; task 1: respectively 11.17 and 4.10, $Z=3.223$, $p < .001$; task 2: 11.39 and 4.22, $Z=3.092$, $p < .01$; task 3: 11.43 and 4.06, $Z=3.593$, $p < .001$), such as the effect of orientation (horizontal or vertical; task 1: respectively 9.04 and 6.22, $Z=2.548$, $p < .02$; task 2: 9.38 and 6.24, $Z=2.417$, $p < .02$; task 3: 9.60 and 5.89, $Z=3.332$, $p < .001$).

A hierarchical cluster analysis enables to gather the eight gauges into clusters which would correspond to different satisfaction levels (Figure 5b). Three clusters resulted from the analysis: a first cluster with the highest satisfaction level (Gauge 1-CPH: mean score: 13.11; Gauge 2-CBV: 13.17; Gauge 3-CPV: 9.87; and Gauge 4-CBV: 9.17); a second cluster with a mid-satisfaction level (Gauge 5-LPH: 5.70; and Gauge 6-LBH: 5.37); a third cluster with the lower satisfaction level (Gauge 7-LPV: 2.48; and Gauge 8-LBV: 2.94).

4 Discussion

Based on these results, answers to the research questions are listed below.

4.1 Does gauge design impact efficiency, visual capture and satisfaction?

First, not significant differences were observed between the different gauges attributes in terms of reading accuracy. All gauges offered drivers the possibility to complete the three different reading tasks very accurately. In the most difficult reading task, where drivers were expected to give an exact value (i.e. Task 1: quantitative reading), the average accuracy error was of about 2.5%. The accuracy was even better for quantitative and check reading, with inaccuracy frequency respectively under 2% and 1%. This could be explained by the experimental design where drivers could look at the gauge as long as needed to complete the reading task. Thus, the most sensitive variable to assess efficiency was the task completion time. These results were supplemented by on-gauge glance duration in order to dissociate the

time required by drivers to perceive the required information on the gauge displayed (i.e. on-gauge glance duration) from the time required to perceive, process and respond to that information. The results collected in terms of task completion time and on-gauge glance duration were very consistent and were found to be dependent of the reading task considered. Depending on the reading task, each of the three gauges attributes manipulated (i.e. shape, indicator and orientation) was found to impact visual capture and completion times. Those differences are discussed in the following paragraphs.

Second, generally speaking, no dramatic effect size changes from one gauge design to the other were observed. At most, a difference of on-gauge glance duration of 280ms was observed between two gauge designs. Although such duration is short in absolute terms, in the truck-driving context this time difference might have a dramatic impact on safety. For instance while driving at 110 kph on a highway, the vehicle is moving by about 8.5 meters during 280ms. Depending on the context, such a distance might be sufficient to prevent or cause a crash for instance.

Third, objective results were found inconsistent with subjective results collected on drivers satisfaction. Drivers reported a clear preference for circular gauges even if little difference in terms of performance was found between circular and linear gauges. Similarly, Gauge 4 (circular-vertical-bargraph) was part of the higher satisfaction cluster, even if its performance measures were lower than other gauges. On the contrary, Gauge 5 (linear-horizontal-pointer) implied good objective results and was part of the mid-satisfaction cluster. Such a pattern of results has already been observed for driving assistance for instance with less effective assistance devices being preferred by drivers over more effective devices (Navarro et al., 2010). Driver preference could rely on other factors than performance, such as aesthetics or familiarity (Alexandre et al, 2018; Kurosu & Kashimura, 1995). This inconsistency between objective and subjective results cause a dilemma to in-vehicle dashboard designers. What should be favored customers' safety or customers' satisfaction? At a first glance one might think that picking safety is best even is that would come with a

lower level of satisfaction. But what if customers' simply buy or use another vehicle with a more satisfying interface? A design offering a good compromise between efficiency and satisfaction could be considered as a valuable alternative.

4.2 What attributes really matter in gauge definition?

The shape of the gauge had a high impact on satisfaction. Circular gauges were clearly preferred by drivers compared to linear gauges. However, the shape was not determining on objective measures. An effect of the shape was only found for the qualitative reading (Task 2), with a low impact on task completion (gap of 47ms – 4%) and eyes on-gauge times (gap of 66ms – 9%). The superiority of circular gauges on linear gauges in terms of preference was also observed in previous researches (Carveth & Adams, 1964; Graham, 1956; Green, 1988; Sleight, 1948). Mayer and Laux (1992) reported however no effect on detection reaction times, but an impact on the primary task. In the reported experiment, driving performances analysis was not technically possible. In the future, it would be interesting to investigate how the gauges design impacts driving performance.

The orientation of the gauge had a more significant impact on objective criteria. Horizontal gauges were more efficient and less visually demanding than vertical gauges (gap of 126ms – 10%). Moreover, horizontal gauges were greatly preferred by drivers. These results, consistent with previous findings (Graham, 1956; Murrell, 1965; Sleight, 1948), have been explained by physiological reasons. Indeed, the visual field being wider than taller, horizontal eye movements would be easier than vertical ones (Green, 1988).

The indicator type had a low implication in gauge efficiency (gap of 50ms – 3%) and visual demand (gap of 65ms – 8%). Connell (1950) proposed that the surface of the indicator would help detection, which could explain the benefit of a pointer against a bargraph. Indicator was also not decisive in drivers' order of preference.

4.3 Which kinds of gauge displays are best for specific tasks?

For gauges requiring quantitative reading (Task 1; e.g. tachometer), horizontal gauges were more efficient and less demanding visually. Eyes on-gauge duration was decreased by 126ms (10%) compared to vertical gauges. The indicator type also impacted visual capture, but less significantly, with an eyes on-gauge duration decreased by 65ms (5%). Linear-vertical-pointer gauges (Gauge 7) should be avoided, considering that they implied a visual capture increased by about 280ms (20%) compared to other gauge design (Gauge 1: circular-horizontal-pointer or Gauge 5: linear-horizontal-pointer should be preferred). This difference is particularly significant, considering that 280ms represents a driven distance of 7 meters at 90km/h.

For gauges requiring qualitative reading (Task 2; e.g. fuel gauge), effects of attributes were less substantial. Linear gauges were more efficient and less visually demanding than circular gauges, with a reduction of eyes on-gauge duration by 66ms (9%). Pointer indicators implied a visual capture decrease of 62ms (9%), and horizontal gauges of 49ms (7%). Moreover, the gauge combining these attributes clearly marked out (Gauge 5: linear-horizontal-pointer gauge). Significant gains (between 100ms and 210ms – 16% and 29%) were measured in term of visual capture. On the contrary, circular-vertical-bargraph gauges (Gauge 4) should be avoided for this task, considering that Gauge 4 was less efficient and more visually demanding than four other gauge designs (eyes on-gauge duration increased by 124ms in average – 16%).

For gauges requiring check reading (Task 3; e.g. engine cooling temperature gauge), pointer indicators were more efficient and less visually demanding than bargraph indicators (visual capture decreased by 75ms – 12%). The differences between gauges did not match significance, showing that gauge design would be less impacting for this task.

4.4 Limitations and perspectives

This study contributes to the current knowledge on this topic, by adding satisfaction data, and by deepening evidence on the role and weight of different design attributes on information processing. However, future research should address further issues. First, no meaning (e.g. oil pressure) was assigned to the values displayed. Thus, the resulting requirements can be applied to new natures of gauges. Nevertheless, gauges can be symbolic or pictorial (i.e. graphical resemblance with the conditions represented). Another widely acknowledged human factor principle is to support driver's mental model of reality (Ross et al., 1996). For example, the gauge displaying fuel level can be considered as an analogy of the fuel tank. Based on this principle, fuel gauges would be best vertically, even if vertical gauges were found less efficient in this study. Appropriate trade-offs between competing requirements should be assessed according to the nature of the gauge.

Second, gauges were assessed individually on each of the three reading tasks. In a vehicle, the same gauge can be used for different reading. For instance, the gauge of air pressure could be used to judge the rate of increase at starting up (i.e. qualitative reading), to set the pressure at a specific value (i.e. quantitative reading), or to ensure that the system is not impaired (i.e. check reading). The requirements for these different uses may conflict, and it will be necessary to evaluate which is the main reading task (based on relevancy for driving, criticality, urgency, and frequency of use criteria).

Third, gauges were here presented in isolation for finer experimental control. Reading can yet be affected by the layout and the clutter of the cluster. High information clutter may cause overload, increased errors, and difficulties in finding appropriate information (Stevens, Quimby, Board, Kersloot, & Burns, 2002). Gauges may also be operated interdependently (e.g. speedometer and tachometer readings) and the arrangement of multiple gauges has been showed relevant (Green, 1988; Warrick & Grether, 1948). A perspective would be to evaluate if each gauge of a truck dashboard should be designed according to its main reading type (based on the results of this study), or if consistency should be applied. Mayer

and Laux (1992) provided a start of an answer reporting that combining dissimilar designs would not make it harder to detect critical values on one gauge.

5 Conclusions

Gauges are major components of trucks dashboards, with direct safety considerations. It is therefore essential to deliver design requirements to practitioners with the following objectives: to provide the information in a quick and accurate way to the driver, and to minimize eyes- on-gauge duration. With the arrival of digital instrument clusters, the human factors literature presents only limited answers to contemporary concerns. This experiment updated existing literature and deepened knowledge on the design attributes impact on gauge information processing. Our findings have direct design implications for surface vehicles dashboards: globally, horizontal gauges and pointer indicators should be favoured in terms of performance and circular gauges are preferred by drivers; gauges requiring quantitative reading should be horizontal and linear-vertical-pointer gauges should be avoided; gauges requiring qualitative reading should be linear and circular-vertical-bargraph gauges should be avoided; gauges requiring check reading should have pointer indicators. The linear-horizontal-pointer gauge performed well on all reading tasks (see Gauge 5, Figure 2).

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