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

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Navarro

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

Taxonomy	Cognitive Ergonomics, Display-Control Relationship, Control Design, Design Control
Corresponding Author	Jordan Navarro
Order of Authors	Mathilde François, Alexandra Fort, Philippe Crave, François Osiurak, Jordan Navarro
Suggested reviewers	Catherine Harvey, Klaus Bengler, Julien Cegarra

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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

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

4 Mathilde François^{1,2}, Alexandra Fort³, Philippe Crave², François Osiurak^{1,4}, Jordan Navarro^{1,4}
5

6 ¹ *Laboratoire d'Etude des Mécanismes Cognitifs, Université de Lyon, Bron, France*

7 ² *Volvo Group Trucks Technology (GTT), Saint Priest, France*

8 ³ *Univ Lyon, IFSTTAR, TS2, LESCOT, F-69675, LYON, France*

9 ⁴ *Institut Universitaire de France, Paris, France*
10

11 **Corresponding author**

12 Jordan Navarro (Jordan.Navarro@univ-lyon2.fr)

13

14 **Running head**

15 Comparison of different gauge designs.

16

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29 digital instrument clusters. Trucks are equipped with many gauges that the driver has to
30 monitor while driving. Digital instrument clusters offer new design possibilities and the
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33 and indicators to perform three reading tasks (quantitative, qualitative and check reading).
34 Results showed that gauge design impacted task completion times, eyes on-gauge duration
35 and satisfaction. Horizontal gauges and pointer indicators were more efficient and less
36 demanding visually. On the subjective side, circular and horizontal gauges were preferred by
37 drivers. Specific gauge designs implied a gain in visual demand up to 250ms. For the design
38 of gauges on digital instrument cluster, information processing can be facilitated thanks to
39 basic design changes.

40

41 **Keywords**

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

44

45 **Précis**

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

50

51 **1 Introduction**

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



63

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

65

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

72 with controlled exposure time (e.g. 120ms in Sleight, 1948), which would affect results and
73 be too far from what occurs in practice (Grether, 1949). The second concerns the lack of a
74 systematic examination of each attribute on each reading type. Indeed, studies often
75 compared few gauge attributes of very different designs, what does not allow judging the
76 weight of each attribute and the interaction between them (Sleight, 1948). Thus, it is of
77 particular interest to investigate how different gauge attributes impact on human monitoring.
78 The third is the specificity of the task proposed in that most of the experiments carried out on
79 the topic exclusively focus on the quantitative reading task (i.e. reading a number). In real life
80 conditions, gauge monitoring implies not only quantitative reading (e.g. exact speed), but
81 also other monitoring tasks, clearly identified in the Human Factors literature: quantitative
82 reading, qualitative reading, and check reading (Endsley, 1988; Sanders and McCormick,
83 1993). 'Quantitative reading' is the processing of a precise numeric value (e.g. the engine
84 speed value). 'Qualitative reading' is used to obtain a trend or change in direction (e.g. the
85 quarter of the fuel level). 'Check reading' determines if a value is within a normal range or
86 not (e.g. engine cooling temperature too hot). More data are thus required to assess the
87 impact of gauge design on different reading tasks (i.e. qualitative reading and check
88 reading). The fourth limitation is that some studies analyzed gauge performance with
89 specified nature (e.g. air speed indicator; Grether & Connell, 1948), what makes these
90 results less transferable to other natures or new gauges. Considering "generic" gauges
91 (without nature) would allow attributing results to design changes only, rather on the
92 semantics associated. The fifth is the issue of transferability of results to the truck domain.
93 More particularly, truck drivers' eye distance to the instrument cluster is greater and implies
94 a larger visual angle compared to car driving. Moreover, truck drivers spend much time on
95 the road in a professional context (up to 56h in any given work week; Bedinger et al., 2015).
96 Their expertise and their particular relation to the vehicle could impact their gauge monitoring
97 process. To bypass these five methodological limitations, the present study proposes
98 respectively: (1) to assess gauge reading *during a driving activity*; (2) to examine the effect

99 of three gauge attributes *in a systematic way*; (3) to present drivers with *three gauge reading*
100 *tasks*; (4) to present a *generic* gauge to increase the generalization of our results; and (5) to
101 assess *truck drivers*. That being said, the next issue concerns the gauge attributes of
102 interest. Today, gauge design is quite inconsistent across trucks manufacturers.
103 Nevertheless, extensive research has been carried out for cars drivers (Green, 1984; Green,
104 1988; Mayer & Laux, 1992) and aircraft pilots (Baker & Grether, 1954; Connell, 1950;
105 Grether, 1949; Grether & Connell, 1948). Three main gauge types were investigated on the
106 different reading tasks: counters or numeric displays, fixed pointer with moving scale, and
107 moving pointer with fixed scale (Baker and Grether, 1954). Counters are reported fast and
108 accurate for quantitative reading, but less suitable for qualitative and check reading (Baker &
109 Grether, 1954; Chapanis, 1960; Green, 1988; Grether, 1949; Sanders & Mc Cormick, 1993).
110 Fixed pointer with moving scale gauges would be globally poorly efficient on the three
111 reading tasks compared to other gauge types (Baker & Grether, 1954; Chapanis, 1960;
112 Connell, 1950; Green, 1988; Grether & Connell, 1958). Moving pointer with fixed scale
113 display would be best for qualitative and check reading, and perform well on quantitative
114 reading (Baker & Grether, 1954; Chapanis, 1960; Green, 1984; Green, 1988; Grether, 1949;
115 Grether & Connell, 1958; Sanders & Mc Cormick, 1993). This gauge type is also the main
116 display used in current truck models. Nevertheless, many types of moving pointer with fixed
117 scale exist, with different design attributes such as the marking of the scale, the way of
118 numbering, the shape and orientation of the gauge, or the indicator type. These attributes
119 have been subjects of several experiments and recommendations have been proposed. For
120 instance, color coding would help the understanding and the detection of critical reading
121 (Green, 1984; Mayer & Laux, 1992); numbers for dials can be inside or outside the scale
122 (Kappauf, 1951); scales should be marked in numbers that are even multiples of 10 (Green,
123 1988); aligning pointers to the normal value when multiple gauges have to be checked close
124 to each other would reduce reading time and errors (Green, 1988; Warrick & Grether, 1948);
125 etc. In sum, previous experiments available in the literature have investigated a large set of

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

130 In the past, those three gauges attributes have been reported to impact reading
131 performance. In an early study in which participants were asked to perform quantitative
132 reading (e.g. read an exact value on a scale), accuracy of reading the gauges were ranked
133 as follows: open-window, circular, semi-circular, horizontal linear and vertical linear (Sleight,
134 1948). During brief presentation of gauges (10 sec films), the number of quantitative reading
135 errors was found much higher for vertical linear gauges as compared to both horizontal
136 linear and circular gauges (Graham, 1956). Circular gauges were also found more effective
137 than vertical linear gauges when assessing the number of correct quantitative readings over
138 five experimental sessions (Carveth & Adams, 1964). Grether and Connell (1948, in Murrell,
139 1965, p.162) have suggested that vertical linear gauges are more effective than circular
140 gauges because an upward movement of the pointer is always associated to an increase in
141 value. The design of pointers has also been under the scope of investigation, but the design
142 of a physical pointer itself only has a small effect on performances (see Green, 1988 for a
143 review). Regarding the shape, orientation and indicator of gauges on preferences, previous
144 research reported that circular gauges might be preferred to linear gauges (Carveth &
145 Adams, 1964; Graham, 1956; Green, 1988; Sleight, 1948), horizontal gauges to vertical
146 gauges (Graham, 1956; Murrell, 1965; Sleight, 1948), and pointers to bargraphs (Mayer &
147 Laux, 1992).

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

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

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

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

158 **2 Material and methods**

159 *2.1 Participants*

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

164

165 *2.2 Equipment*

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

176

177 *2.3 Material*

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

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

188

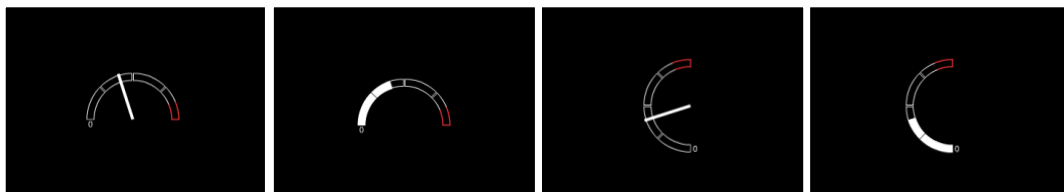
189

1.CPH

2.CBH

3.CPV

4.CBV



190

191

5.LPH

6.LBH

7.LPV

8.LBV

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

195

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

- 198 ▪ Task 1 (quantitative reading): ‘What is the gauge value between 0 and 100?’
 199 (answer: a number between 0 and 100)

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

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

208

209 2.4 Procedure

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

222

223 2.5 Data acquisition and analysis

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

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

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

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

243

244 **3 Results**

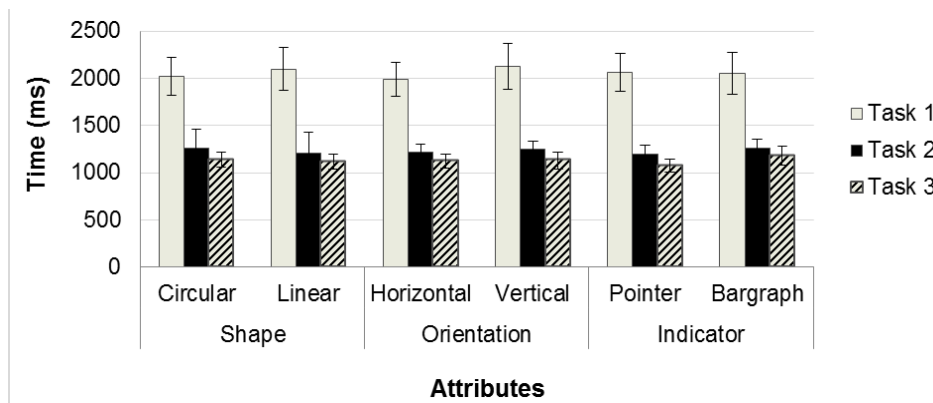
245 *3.1 Efficiency*

246 **Global analysis.** Task completion times (Figure 3) and accuracy scores were collected. A
247 significant main effect of the task was found ($F(2,34) = 95.44, p < .001$), post-hoc analyses
248 showed that task 1(2058ms) implied longer task completion times than task 2 (1232ms,
249 $p < .001$) and 3 (1128ms, $p < .001$).

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

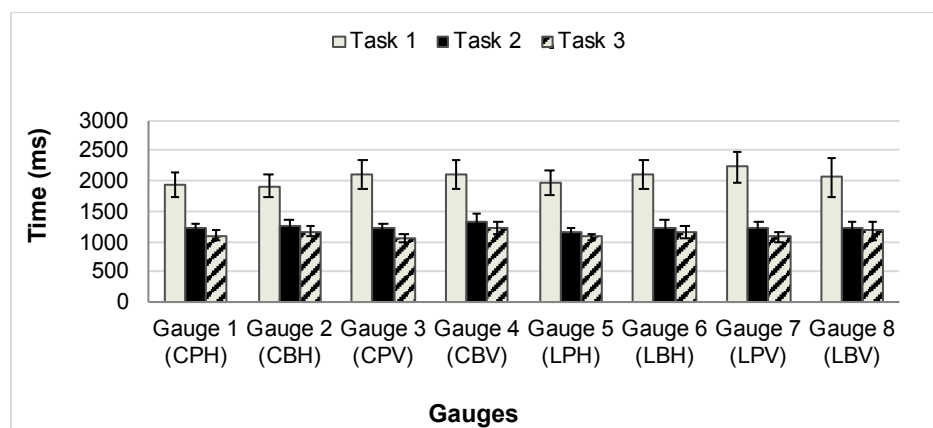
252 tasks were performed slower with bargraph indicators (1498ms) than with pointers (1447ms;
 253 $F(1,17) = 8.334, p < .01$). The three-way interaction shape*orientation*indicator was
 254 significant ($F(1,17) = 13.84, p < .01$) revealing that gauge 5-LPH (1401ms) was significantly
 255 more efficient than four other gauges (gauge 4-CBV: 1551ms, $p < .001$; gauge 6-LBH:
 256 1495ms, $p < .001$; gauge 7-LPV: 1512ms, $p < .01$; gauge 8-LBV: 1490ms, $p < .03$). On the
 257 contrary, Gauge 4-CBV was found less efficient than four other gauges (gauge 1-CPH:
 258 1551ms, $p < .001$; gauge 2-CBH: 1495ms, $p < .001$; gauge 3-CPV: 1512ms, $p < .01$; gauge 5-
 259 LPH). Gauge 7-LPV was significantly less efficient than gauge 5- LPH and gauge 1-CPH
 260 (1418ms, $p < .02$).

261



262

a.



b.

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.

263

264

265

266

267

268 **Task by task analyses.** For the **task 1** (quantitative reading), tasks completion times were
269 lower with horizontal (1987ms) than with vertical gauges (2128ms; $F(1,17) = 11.45, p<.01$).
270 The three-way interaction was significant ($F(1,17) = 7.44, p<.02$), and Tukey HSD post-hoc
271 test showed that Task 1 was completed significantly faster with Gauge 1-CPH (1940ms,
272 $p<.001$), Gauge 2-CBH (1922ms, $p<.001$) and Gauge 5-LPH (1980ms, $p<.01$) than with
273 Gauge 7-LPV (2232ms). Reading accuracy was very good with about 2.5% of errors around
274 the real value on the average and not significantly different between gauge attributes.

275 For the **task 2** (qualitative reading), tasks completion times were lower with linear (1208ms)
276 than with circular gauges (1255ms; $F(1,17) = 8.19, p<.02$). Horizontal gauges (1215ms)
277 were slightly more efficient than vertical gauges (1248ms; $F(1,17) = 11.62, p<.01$). Similarly,
278 pointers (1201ms) were slightly more efficient than bargraph indicators (1262ms; $F(1,17) =$
279 $8.39, p<.01$). Accuracy was very good, with less than 2% of incorrect quarter responses, and
280 not significantly different between gauge attributes. The three-way interaction was significant
281 ($F(1,17) = 5.55, p<.04$), and Tukey HSD post-hoc test reported that task 2 was completed
282 faster with the Gauge 1-CPH (1214ms, $p<.05$), Gauge 3-CPV (1215ms, $p<.05$) and Gauge
283 5-LPH (1147ms, $p<.05$) than with Gauge 4-CBV (1327ms). Gauge 5-LPH was more efficient
284 than Gauge 2-CBH (1266ms, $p<.04$) and Gauge 4-CBV. The Friedman test reported no
285 significant difference of accuracy between gauge attributes.

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

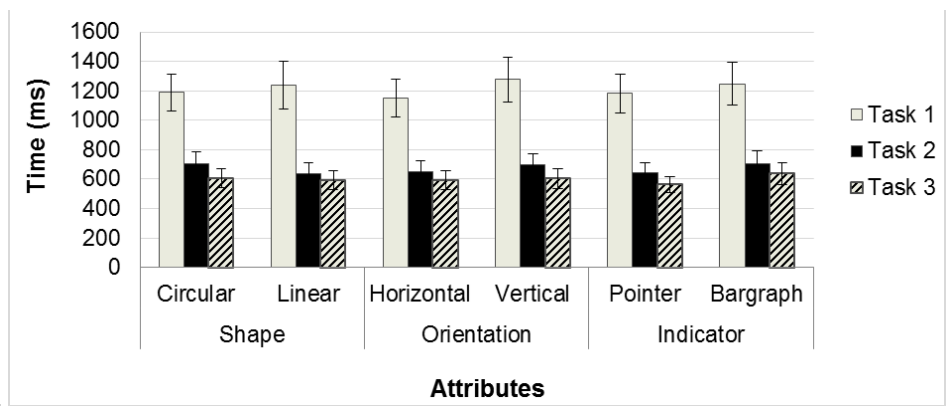
290

291 3.2 *Visual capture*

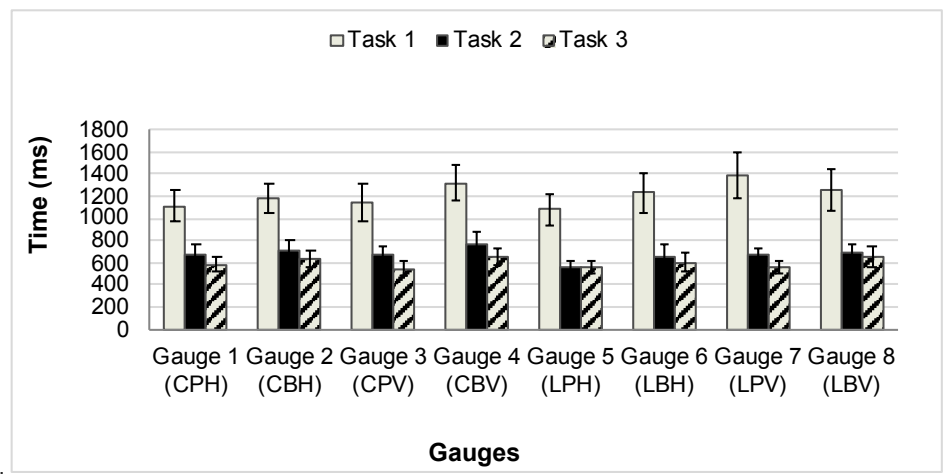
292 **Global analyses.** Visual capture was assessed through the total on-gauge glance duration
293 (Figure 4). A main effect of the task was found significant ($F(2,34) = 115.12, p<.001$),

294 showing that task 1(1214ms) implied longer on-gauge glances than task 2 (673ms, $p<.001$)
 295 and task 3 (600ms, $p<.001$). Regardless of the task, vertical gauges (860ms) appeared more
 296 visually demanding than horizontal gauges (798ms; $F(1,17) = 25.46, p<.001$). On-gauge
 297 glance durations were also longer with bargraph gauges (863ms) than with pointer indicator
 298 gauges (795ms; $F(1,17) = 20.13, p<.001$). The three-way interaction
 299 shape*orientation*indicator was also significant ($F(1,17) = 9.66, p<.01$), and post-hoc test
 300 reported that Gauge 5-LPH (731ms) was significantly less visually demanding than four
 301 other gauges (Gauge 2-CBH: 840ms, $p<.03$; Gauge 4-CBV: 915ms, $p<.001$; Gauge 7-LPV:
 302 870ms, $p<.01$; and Gauge 8-LBV: 864ms, $p<.01$). On the contrary, Gauge 4-CBV implied
 303 longer on-gauge glances than four other gauges (Gauge 1-CPH: $p<.01$; Gauge 3-CPV:
 304 $p<.01$; and Gauge 5-LPH).

305
 306



307



308

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

311

312

313 **Task by task analyses.** For the **task 1** (quantitative reading), the main effect of orientation
314 was significant ($F(1,17) = 11.71, p < .01$) showing that vertical gauges (1277ms) were more
315 visually demanding than horizontal gauges (1151ms). The three-way interaction
316 shape*orientation*indicator was also significant ($F(1,17) = 6.96, p < .02$) showing that Gauge
317 7-LPV (1382ms) was more visually demanding than Gauge 1-CPH (1112ms, $p < .03$) and
318 Gauge 5-LPH (1084ms, $p < .02$).

319 For the **task 2** (qualitative reading), main effects of shape, orientation, and indicator factors
320 reached significance. Circular gauges (706ms) were more visually demanding than linear
321 gauges (640ms; $F(1,17) = 19.37, p < .001$). Vertical gauges (698ms) were more visually
322 demanding than horizontal gauges (648ms; $F(1,17) = 27.34, p < .001$). Bargraph gauges
323 (704ms) were more visually demanding than pointer gauges (642ms; $F(1,17) = 15.67,$
324 $p < .001$). The three-way interaction was significant ($F(1,17) = 8.24, p < .02$), and Tukey HSD
325 post-hoc test reported that task 2 implied longer eyes on-gauge duration with Gauge 4-CBV
326 (769ms) than with five other gauges (Gauge 1-CPH: 675ms, $p < .05$; Gauge 3-CPV: 673ms,
327 $p < .04$; Gauge 5-LPH: 553ms, $p < .001$; Gauge 6-LBH: 658ms, $p < .02$; and Gauge 7-LPV:
328 665ms, $p < .03$). On the contrary, Gauge 5-LPH was less visually demanding than all other
329 gauges (Gauge 1-CPH: $p < .01$; Gauge 2-CBH: 706ms, $p < .001$; Gauge 3-CPV: $p < .01$; Gauge
330 4-CBV; Gauge 6-LBH: $p < .02$; Gauge 7-LPV: $p < .02$; and Gauge 8-LBV: 683ms, $p < .01$).

331 For the **task 3** (check reading), the effect of the indicator was significant: pointer gauges
332 (562ms) were less visually demanding than bargraph gauges (637ms; $F(1,17) = 25.59,$
333 $p < .001$). The two-way interaction orientation*indicator was also significant ($F(1,17) = 4.75,$
334 $p < .05$), showing that the effect of the indicator is more pronounced for vertical (vertical-

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

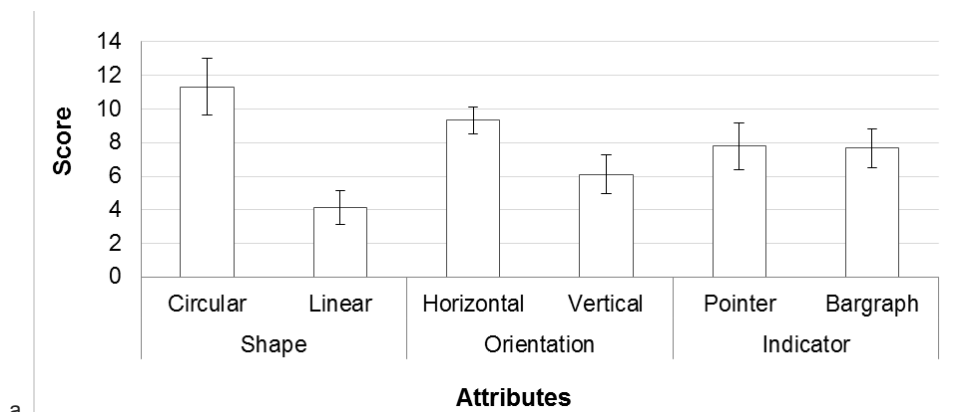
337

338 3.3 Satisfaction

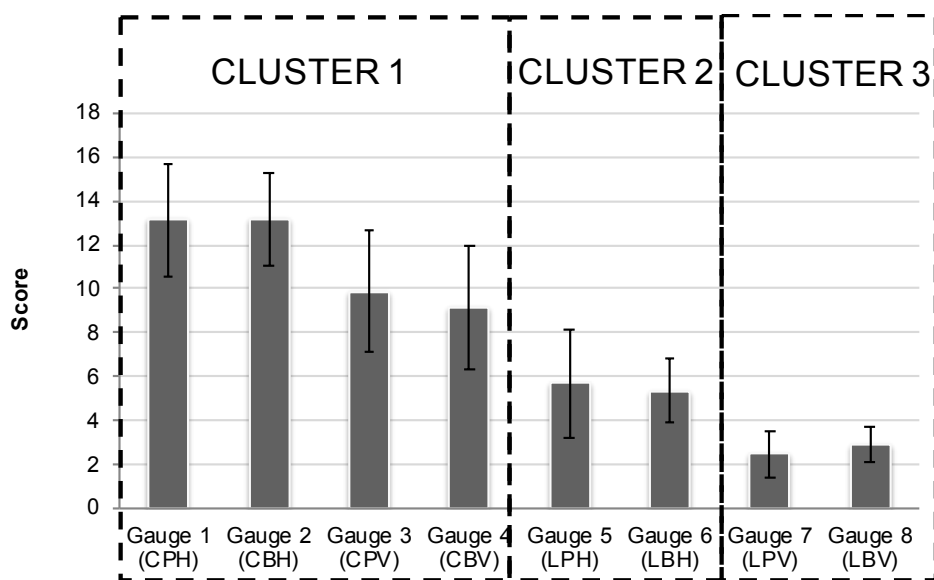
339 **Global analyses.** Pairwise comparisons were led for each attribute using Wilcoxon tests
 340 (Figure 5a). Globally, circular gauges (mean score: 11.17) are preferred to linear gauges
 341 (4.10; $Z = 3.223$, $p < .001$). Similarly, horizontal gauges (9.04) are preferred to vertical gauges
 342 (6.22; $Z = 3.462$, $p < .001$).

343

344



a.



b.

345

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348

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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.

350 **Task by task analyses.** Friedman test reported significant differences between gauges
351 ($\chi^2(7) = 70.70, p < .001$). Because very similar satisfaction results were found for the three
352 reading tasks, the analyses are presented together. The effect of the shape was significant
353 (circular or linear; task 1: respectively 11.17 and 4.10, $Z=3.223, p < .001$; task 2: 11.39 and
354 4.22, $Z=3.092, p < .01$; task 3: 11.43 and 4.06, $Z=3.593, p < .001$), such as the effect of
355 orientation (horizontal or vertical; task 1: respectively 9.04 and 6.22, $Z=2.548, p < .02$; task 2:
356 9.38 and 6.24, $Z=2.417, p < .02$; task 3: 9.60 and 5.89, $Z=3.332, p < .001$).

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

363

364 **4 Discussion**

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

366 *4.1 Does gauge design impact efficiency, visual capture and satisfaction?*

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

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

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

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

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

406

407 *4.2 What attributes really matter in gauge definition?*

408 The shape of the gauge had a high impact on satisfaction. Circular gauges were clearly
409 preferred by drivers compared to linear gauges. However, the shape was not determining on
410 objective measures. An effect of the shape was only found for the qualitative reading (Task
411 2), with a low impact on task completion (gap of 47ms – 4%) and eyes on-gauge times (gap
412 of 66ms – 9%). The superiority of circular gauges on linear gauges in terms of preference
413 was also observed in previous researches (Carveth & Adams, 1964; Graham, 1956; Green,
414 1988; Sleight, 1948). Mayer and Laux (1992) reported however no effect on detection
415 reaction times, but an impact on the primary task. In the reported experiment, driving
416 performances analysis was not technically possible. In the future, it would be interesting to
417 investigate how the gauges design impacts driving performance.

418 The orientation of the gauge had a more significant impact on objective criteria. Horizontal
419 gauges were more efficient and less visually demanding than vertical gauges (gap of 126ms
420 – 10%). Moreover, horizontal gauges were greatly preferred by drivers. These results,
421 consistent with previous findings (Graham, 1956; Murrell, 1965; Sleight, 1948), have been
422 explained by physiological reasons. Indeed, the visual field being wider than taller, horizontal
423 eye movements would be easier than vertical ones (Green, 1988).

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

428

429 4.3 *Which kinds of gauge displays are best for specific tasks?*

430 For gauges requiring quantitative reading (Task 1; e.g. tachometer), horizontal gauges were
431 more efficient and less demanding visually. Eyes on-gauge duration was decreased by
432 126ms (10%) compared to vertical gauges. The indicator type also impacted visual capture,
433 but less significantly, with an eyes on-gauge duration decreased by 65ms (5%). Linear-
434 vertical-pointer gauges (Gauge 7) should be avoided, considering that they implied a visual
435 capture increased by about 280ms (20%) compared to other gauge design (Gauge 1:
436 circular-horizontal-pointer or Gauge 5: linear-horizontal-pointer should be preferred). This
437 difference is particularly significant, considering that 280ms represents a driven distance of 7
438 meters at 90km/h.

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

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

453

454 4.4 *Limitations and perspectives*

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

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

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

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

483

484

485 **5 Conclusions**

486 Gauges are major components of trucks dashboards, with direct safety considerations. It is
487 therefore essential to deliver design requirements to practitioners with the following
488 objectives: to provide the information in a quick and accurate way to the driver, and to
489 minimize eyes- on-gauge duration. With the arrival of digital instrument clusters, the human
490 factors literature presents only limited answers to contemporary concerns. This experiment
491 updated existing literature and deepened knowledge on the design attributes impact on
492 gauge information processing. Our findings have direct design implications for surface
493 vehicles dashboards: globally, horizontal gauges and pointer indicators should be favoured
494 in terms of performance and circular gauges are preferred by drivers; gauges requiring
495 quantitative reading should be horizontal and linear-vertical-pointer gauges should be
496 avoided; gauges requiring qualitative reading should be linear and circular-vertical-bargraph
497 gauges should be avoided; gauges requiring check reading should have pointer indicators.
498 The linear-horizontal-pointer gauge performed well on all reading tasks (see Gauge 5, Figure
499 2).

500

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568 **Biographies**

569

570 **Mathilde François** is an industrial PhD student in Cognitive Science at Volvo Group Trucks
571 Technology and University Lyon 2 (E.M.C laboratory). She graduated from University Lyon 2
572 with a Master's degree in Cognitive Science in 2013.

573 **Alexandra Fort** is a researcher at the Laboratory Ergonomics and Cognitive Sciences
574 applied to Transport (IFSTTAR-TS2). She obtained a PhD in Cognitive Science at University
575 Lyon 2 in 2002.

576 **Philippe Crave** is an HMI designer for more than 10 years at Volvo Group Trucks
577 Technology. He received his Master's degree in Mechanical engineering from University of
578 Technology of Compiègne (UTC) in 1999.

579 **François Osiurak** is a Full Professor in Neuropsychology at the University Lyon 2 (E.M.C.
580 laboratory) and appointed as Junior Member at of the "Institut Universitaire de France". He
581 received a PhD in Psychology from the University of Angers in 2007.

582 **Jordan Navarro** is lecturer in cognitive psychology at the University Lyon 2 (E.M.C
583 laboratory) and appointed as Junior Member at of the "Institut Universitaire de France". He
584 graduated from the University of Nantes with a PhD in Psychology in 2008.