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Conventional vehicle display panels: The drivers' operative images and directions for their redesign

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ABSTRACT

The proliferation of new displays in modern vehicles sets the challenge to revisit the design of the conventional display units, toward more simplified appearance. The present study aims to evaluate the usefulness of the information provided to the drivers by the conventional vehicle display units, in order to trace directions that would lead to a simplification of the future display panels. Based on the concept of operative images, two working hypotheses were formulated: (i) the experienced drivers have developed an operative image-reference (OI-R) for the display panel of their own vehicle(s), reflecting the relative importance they attribute to the information emitted by the various displays of the panel, and (ii) the experienced drivers' drawings of the display panel of their own vehicle will be guided by their OI-R for it – providing therefore traces of the content of their OI-R, while the less experienced drivers' drawings will be closer to the actual display panel of their own vehicle. The method of drawing from memory was used to obtain traces of the operative images of both experienced and less experienced non-professional drivers. The obtained 335 drawings were compared to the actual display panels, as to their overall resemblance and to specific features. The results of the data analysis are in accordance to our working hypotheses. Considering the main features of the experienced drivers' OI-R, directions for the simplification of the appearance of conventional display units are proposed.

1. Introduction

Throughout the development of vehicle display panel, the kind of information provided to the driver has all been related to the lower-level operational components of vehicle control (Fowkes, 1984). However, the on-going development of in-vehicle systems within the last two decades, offers the potential to expand the kind of information provided to the driver to tactical and even strategic aspects of driving (Michon, 1985).

In various aspects the development of in-vehicle systems is a corollary of the increased complexity of modern traffic systems. As Hollnagel (2006) states, driving is a highly paced activity. On the early automotive years, driving pace was influenced by both the road surface conditions and the operational requirements of vehicle control. If the driver was to maintain a 'safe travel', it was presupposed that he had a technical understanding of vehicle functioning. Consequently, vehicle displays were designed with the intention to convey to the driver all the necessary information that enabled him/her to infer the current vehicle status and select a proper course of action to avoid undesired situations (e.g. dash-mounted ammeter, oil- and water-temperature).

In the mid-years of automotive history, approximately from 1930 to 1970, new technologies became available, aiming either to increase vehicle engine efficiency (e.g. air-cooled engine) or to reduce the driver's physical effort (e.g. automatic transmission and power steering wheel). At the same time, the traffic environment became gradually more complex (e.g. increased number of vehicles, traffic signs). Due to these changes, driving pace was gradually more influenced by the traffic infrastructure rather than by the operational requirements of the vehicle control. As a consequence, the dominant displays became the speedometer and the RPM counter, and around them, a minimum set of displays was placed (e.g. fuel and temperature gauges). Other information related to engine status could be presented via tell-tale lights, either as system status information or warning functions (Fowkes, 1984).

Over the last 40 years, changes in-vehicles' technology decreased the driver's need for a precise mental model of the vehicle engine in order to operate it. On the other hand, changes in traffic conditions and the advent of new technologies increased the opportunities for the development of new in-vehicle systems. Such

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systems fall in two broad categories: (i) advanced driver-assistance systems (ADAS) aiming to help the driver cope with traffic complexities, e.g. forward collision warning, lane-departure warning, vision enhancement systems, and (ii) in-vehicle information systems (IVIS) aiming to enhance the driver's mobility and comfort, e.g. navigation aids and traffic information systems, media players, web browsers (Amditis et al., 2010).

This proliferation of in-vehicle functionality has led to an increased concern of researchers regarding the potential side-effects of these systems in terms of driver distraction/workload (Bayly et al., 2009; Wittmann et al., 2006; Young and Stanton, 2007) and driver behavior adaptation (Engstrom and Hollnagel, 2007; Saad, 2006). It also calls software and graphic designers to "design a leaner, simplified human/machine interface within the driver's visual field that still manages to convey all of the required information" (Wesner, 2005, p.89).

To this end, some possible solutions for the design of the future automotive human–machine interface (HMI) have been demonstrated and evaluated under the framework of the COMUNICAR European project (Bellotti et al., 2004, 2005) and the AIDE European project (Amditis et al., 2010). These solutions range from a partial integration of the different functions in separated clusters, to a total integration of the different functions in a fully reconfigurable cluster, and aim to create a "cognitive prosthesis" able to adapt the in-vehicle systems to the individual driver (Cacciabue and Carsten, 2010). However, results from on-road evaluation tests show that the integrated and adaptive HMI could have a potential safety benefit in the most critical cases, but, in cost of a higher perceived workload. Taking into account the above results, further research is needed.

A different approach toward the simplification of the HMI would be to examine the usefulness of the various displays, and in particular of the conventional ones. It is worth to mention that there is evidence from older studies that drivers do not frequently consult the conventional display units, but rely on cues such as visual flow, engine noise, etc. (Denton, 1969; Groeger et al., 1999; Green, 1983; McClane and Wierwille, 1975; Milosevic and Milic, 1990).

The present study adopts such a direction and attempts to explore the relative importance of the most common display units (i.e. speedometer, RPM counter, fuel and temperature gauges), by searching traces of the mental representation that drivers develop for the display panel of their own vehicle, through experience. To this end, the method of drawing from memory was adopted. This investigation is based on the assumption that mental representations reflect the relative importance attributed by the experienced drivers to both the diverse display units as well as to their specific features. We maintain that this should be the first step in order to trace the directions toward a possible simplification of the future display panels.

The rest of this paper is structured as follows. In Section 2 the theoretical background of the study and the working hypotheses that guided it are outlined. In Section 3, the method for drawings' gathering and the way they were treated and analyzed are described. In Section 4, the data analysis and results are reported. Finally, in Section 5, the main findings of the study and their implications for future designs of display panels are discussed.

2. Mental representations

In the literature there is a long tradition of discerning between two main types of representations: "mental" or "internal" representations and "non-mental" or "external" ones (see also Richardson and Ball, 2009 for a review). The above distinction derives from the assumption that our memories from past experiences are neither exact copies of earlier percepts nor random memory traces which are recalled by chance (Neisser, 1976). Instead, there is evidence that the matter of recall is the result of a genuine reconstruction. There are two generic notions related to the mental representations *schema*, and *operative image*, that are discussed below. Two other generic notions are *mental model* and *conceptual model*, which are not discussed here, since they refer to the humans' functional understanding of how a system or a device works, rather than how the system image has been internalized.

2.1. Schema

Bartlett (1932) was the first who provided evidence for the reconstructive function of memory. In a series of experiments Bartlett asked participants to read and then to recall stories from different cultures. It came out that the participants' educational and cultural background caused systematic distortions in the way the stories were recalled – and thus remembered. More specifically, as they were recalled, they were altered in a way that the new version was culturally conventional and meaningful for the subjects. In accordance to such observations, Bartlett introduced the concept of "*schema*". Schema was defined as "an active organized setting of past reactions or experience" that "is producing an orientation of the organism toward whatever it is directed to at the moment" (Bartlett, 1932, p.208). An important feature of schemas is that they are not stored in memory as static representations, but they are "living and developing, are a complex expression of the life of the moment, and help to determine our daily modes of conduct" (p.214).

In the decade of 1970 many researchers attempted to extend and formalize the schema concept (see Alba and Hasher, 1983 for a coherent review). In the domain of artificial intelligence (AI), a more explicit account of the cognitive structures that underlie schematic knowledge organization was provided, through the notions of "*frames*" (Minsky, 1975) and "*scripts*" (Abelson, 1981; Schank and Abelson, 1977). The basic idea was that our experiences of familiar scenes, events and situations are represented internally as generic knowledge structures that contain informational slots or variables. If the inputs provided by the context do not sufficiently supply with specific information that would fill these slots, then they are inferred and filled with default values, which correspond to stereotypical values that originate from past experiences. In this way, schematic knowledge aids to normalize experience and to make events more consistent with prior experience. As Whitney (2001) pointed out, it soon became clear to those worked in AI that modifications of the whole notion of a schema were necessary in order to account for people's flexibility in comprehension and memory processing. As a result, a revised view of the schema concept had emerged, according to which a schema was "always constructed on the spot based on the current context" (Whitney, 2001, 13525).

2.2. Operative image

The concept of *operative image* was first proposed by Ochanine (1970) and Ochanine and Chebek (1968), in the context of work activity analysis. He aimed to highlight the fact that mental representations for action do not only reflect reality, but also they primarily reflect functional deformations of the objects that are dealt with, which are particular relevant for the action of each individual (Daniellou, 2005). The origin of this notion is based on the assumption that operators who are involved in the same system but have different tasks, do not construct the same "images"; each of them tends to memorize only some elements of the environment, and distortions tend to occur by emphasizing the task-relevant aspects of these memorized pieces of information (Geron, 2008).

According to Ochanine (op. cit.), operative images are distinguished in two kinds: *operative images-signals* and *operative* *images-references*. The former refer to the images of a perceived object or situation that are created when the observer is guided by a specific goal or task which is related to the object. The latter are closer to the schema notion and are referred to the images that are developed through succeeding repetitions of operative images-signals of an object or a situation, a group of objects or situations, etc. In both cases, the resulting image is not an isomorphic representation of an object or a situation, but a simpler representation that is both laconic (i.e. brief and to the point) and functionally deformed (i.e. with certain features detailed and emphasized, while with other missing), according to the task requirements. Due to the way operative images-signals are formed, they are highly depended on the context through which the task is accomplished. Accordingly, since the operative images-references constitute the integration of the operative images-signals, they are dynamically enriched by the latter through time.

To demonstrate the concept of operative images a number of experiments was carried out (Ochanine, 1971; Ochanine and Kozlov, 1971), using among others the methods of drawing and sculpturing from memory. For instance, in the area of medical diagnosis, Ochanine studied the operative images of an ailing thyroid gland created by three groups of physicians (i.e. endocrinologists, general physicians and non-specialized physicians). At a first phase, the participants examined the gland by palpation, as well as by a visual diagram produced via radioisotopes, and then were asked to represent the ailing-gland in the form of a plasticine model. Results showed that the plasticine models created by the more specialized and experienced physicians were characterized by larger deformations compared to the less specialized and experienced ones. However, the deformations of the gland were neither errors nor deficiencies, but functional deformations, in the sense that they put emphasis in those parts of the thyroid gland that were deformed because of the disease. On the other hand, the plasticine models of the less specialized and experienced physicians were more proper from an anatomical point of view, but less rich in information related to the symptoms of the disease.

It is interesting to note that similar findings have been reported by Myles-Worsley et al. (1988) but have been interpreted by the notion of *schema* (Groeger, 1997). Basically, both notions attempt to describe the same phenomenon: that experts' memory of the objects related to the accomplishment of specific tasks, is both biased and deformed. However, a schema-based account cannot specify in advance which objects will be selectively remembered by the experts. In contrast, the operative image concept clearly supports that experts' images will mainly include the information that has functional significance, as it has been shown by the results of the two above mentioned studies.

Based on the above, the present study was guided by the following working hypotheses:

i. The experienced drivers have developed an operative image-reference (OI-R) for the display panel of their own vehicle(s), reflecting the relative importance they attribute to the information emitted by the various displays of the panel.
ii. The experienced drivers' drawings will be guided by their OI-R for the display panel – providing therefore traces of the content of their OI-R, while the less experienced drivers' drawings will be closer to the actual display panel of their own vehicle.

3. Method

3.1. Participants

Four-hundred-twenty-five (425) Greek non-professional drivers took part in this study on a voluntary base. The participants were randomly selected. Specifically, 85 students from the National Technical University of Athens, Greece, were asked to contact five drivers of their close environment in order to collect the raw data. The students (now on research assistants) were asked to contact only active drivers (i.e. driving on daily basis) having different characteristics in terms of gender, age and years of driving license acquisition. During analysis, a number of drivers' drawings was excluded due to their inoperativeness (e.g. illegible lines, use of written language, etc). This was rather expected since, not all participants felt comfortable or self-confident with sketching. Thus, in total, a sample of 335 drawings of non-professional drivers (235 males and 100 females) was analyzed.

The drivers' age ranged from 19 to 68 years, with a mean age of 33.8 years (SD = 13.7). All participants hold a driving license for at least two months, and had different levels of driving experience, ranged from 2 months to 47 years (mean = 12.5 years; SD = 11.6).

3.2. Procedure

Each participant was contacted in a place where his/her vehicle would be out of sight. After a briefing session, the participants were asked to sketch from memory the display panel of their own vehicle, with as many details as possible, using a white sheet of paper and a pencil. The use of drawing devices (e.g. ruler, divider, etc) was not allowed. No time constraints were imposed and no advice was given to the participants during drawing. After drawing completion, the participants were asked to fill-in a questionnaire. The questionnaire collected the following data: gender, age, year of driving license acquisition, years of possession of their last vehicle and type of their vehicle.

3.3. Data treatment

At a first phase, photos and pictorial diagrams of the display panels of the participants' vehicles were searched through the Internet; the participants' drawings were also scanned. Finally, appropriate files with the drawings and the actual pictures of the dashboards were developed to facilitate the analysis.

At a second phase, we examined the overall resemblance of the drawn display panels to the actual ones. Three independent evaluators were asked to compare the drawings with the actual display panels regarding their overall resemblance. A five-point scale was used to evaluate the resemblance: "1" was attributed for a lot of differences, "5" for almost similar. The majority (73%) of the resemblance scores attributed by the evaluators was identical, while the rest differed no more than two points. The statistical significance of the inter-rater reliability was 0.746 (MacLennan, 1993). To obtain a unique score of resemblance in the case of disagreement, the scores attributed by the three evaluators were processed as follows. In the cases that only one evaluator disagreed, the other two's score was gathered. When all three evaluators disagreed among them, then their average score was calculated. To obtain a better assessment of the drawn display panels deformations, at a third phase, the drawings of the drivers were analytically compared to the actual display panels according to the following criteria, using appropriate scores.

1. *Number of omitted display units.* A total score for the omitted display units was calculated in the following way. The number of the drawn display units of each drawing was divided by the number of the display units included in the actual dashboard. Thus, the total score for the omitted display units ranged from 0 to 1, with 1 attributed for the case that all display units were drawn by the driver.

Table 1
Allocation of participants into three groups, according to the number of years they held a driving license.

Groups of participants	*N*	Gender		Age (yrs.)				Driving experience (yrs.)			
		Male	Female	Mean	SD	Min	Max	Mean	SD	Min	Max
A less experienced	114	69	45	23.2	4.0	19	49	2.9	1.0	0.2	4
B mid experienced	104	82	22	27.5	6.1	22	61	7.5	2.2	4.5	12
C experienced	117	84	33	49.9	9.4	31	68	26.3	8.9	13	47
Total	335	235	100	33.8	13.7	19	68	15.5	14.3	0.2	47

2. *Accuracy of the relative arrangement of the display units.* A total score was calculated in the following way. For each display unit, a "0" score was attributed in the case that a drawn display unit was rearranged as to its relative placement to the rest ones on the actual dashboard, whereas, a "1" score was attributed in the case that there was no arrangement alternation. The sum of the partial scores was then divided by the number of display units that were drawn. Thus, the total score for the accuracy of the relative arrangement of the display units ranged from 0 to 1, with 1 for the case that no re-arrangements were observed.
3. *Accuracy of numbering/labeling the drawn display units.* The examined dashboards comprised four main display units: speedometer, RPM counter, fuel gauge and temperature gauge. A total score for the accuracy of the numbering/labeling of each of the above display units was calculated in the following way. Each drawn display was examined according to the accuracy of the following features: numbering scale, scale intervals, units, pointers direction, and pictorial material (e.g. icons used in fuel and temperature gauges or the so-called "red zone" of the RPM counter). A "0" score was attributed if a particular feature was missing or it was incorrect, whereas, a "1" score was given if it was correct. The sum of the scores was then divided by the number of features included in the actual display unit. Thus, the total score for the accuracy of the numbering/labeling of each display unit ranged from 0 to 1, with 1 in the case of a totally accurate drawing.

4. Data analysis and results

The obtained data were analyzed using as independent variable the driving experience of the participants. For the estimation of driving experience, two alternative criteria could be used (i) the number of years participants held a driving license, or (ii) the number of total driven kilometers, extrapolated from the driven kilometers per year. Due to the low reliability of participants' estimations regarding the number of driven kilometers, the first criterion was selected.

Accordingly, the participants were distributed into three groups: less experienced drivers, holding a driving license for less than 4 years (2–48 months), mid experienced drivers, holding a driving license for 4–12 years (49–144 months), and experienced drivers, holding a license for more than 12 years (149–564 months) (Table 1).

Furthermore, as we searched for possible effect of the display units' layout into participants' performance, the display panels examined in this study, were grouped according to the spatial layout of the four main display units, i.e. speedometer (S), RPM counter (R), fuel gauge (F) and temperature gauge (T). This resulted to the identification of four main types of display units' layouts (Table 2). As it can be seen in Table 2, only one type of the display units' layouts was underrepresented (type 4).

4.1. Overall resemblance of the drawn display panels to the actual ones

As already stated at Section 3.3, three independent evaluators compared the resemblance of the drivers' drawings to the pictures of the actual display panels of the drivers' vehicles. Table 3 presents the mean and the standard deviation values of the scores attributed by the three evaluators to the drawings of the three groups of participants, as well as the unified scores.

Table 2
Types of display units' layout identified in this study and number of drawings corresponding to each one. The inter-position of the four display units of interest (i.e. "S": speedometer; "R": RPM counter; "F": fuel gauge; "T": temperature gauge) within each type of layout, is presented in the middle column.

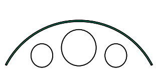
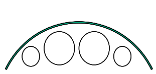
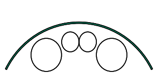
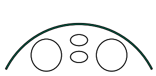
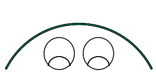
Types of display units' layout		Inter-position of display units	Number of drawings examined			
			Group A	Group B	Group C	All
Type 1:		"S" central "F"–"T" bilateral to "S"	23	16	26	65
Type 2:		"S"–"R" central "F"–"T" bilateral to "S"/"R"	47	39	49	135
Type 3a:		"F"–"T" central "S"–"R" bilateral to "F"/"T"	27	35	24	111
Type 3b:			12	5	8	
Type 4:		"S"–"R" central "F"–"T" inside to "S"/"R"	5	9	10	24
		Total	114	104	117	335

Table 3
Mean and standard deviation values of the scores for the resemblance of the drawn display panels to the actual ones.

Groups of participants'	N	Resemblance of drawn display units to the actual ones							
		Evaluator A		Evaluator B		Evaluator C		Unified score	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
A less experienced	114	3.67	1.2	3.22	1.3	3.67	1.2	3.65	1.2
B mid experienced	104	3.61	1.1	3.16	1.1	3.56	1.2	3.54	1.0
C experienced	117	3.22	1.3	2.66	1.3	3.47	1.3	3.08	1.1

Considering driving experience as the independent variable, the unified scores were subject to statistical analysis using one-way ANOVA for unrelated samples. The analysis showed statistically significant difference among the scores attributed to the three groups of drivers, at the .05 significance level ($F = 8.744$, $p < .000$). A two-sample t-test was then carried out, showing significant difference between the scores attributed to the groups A and C ($t = 3.666$, $p < .000$), as well as to the groups B and C ($t = 3.014$, $p < .003$). There was no statistical difference between the scores of groups A and B ($t = .754$, $p < .452$). We can conclude therefore, that the display panels drawn by the experienced drivers are more deformed than the drawings of the less experienced drivers.

Fig. 1 illustrates some typical examples of experienced and less experienced drivers' drawings, as well as the actual picture of the display panels. As it can be seen, the drawings of the experienced drivers are characterized by more simple and abstract depiction of the display panel in comparison to the drawings of the less experienced ones. In other words, the experienced drivers seem to

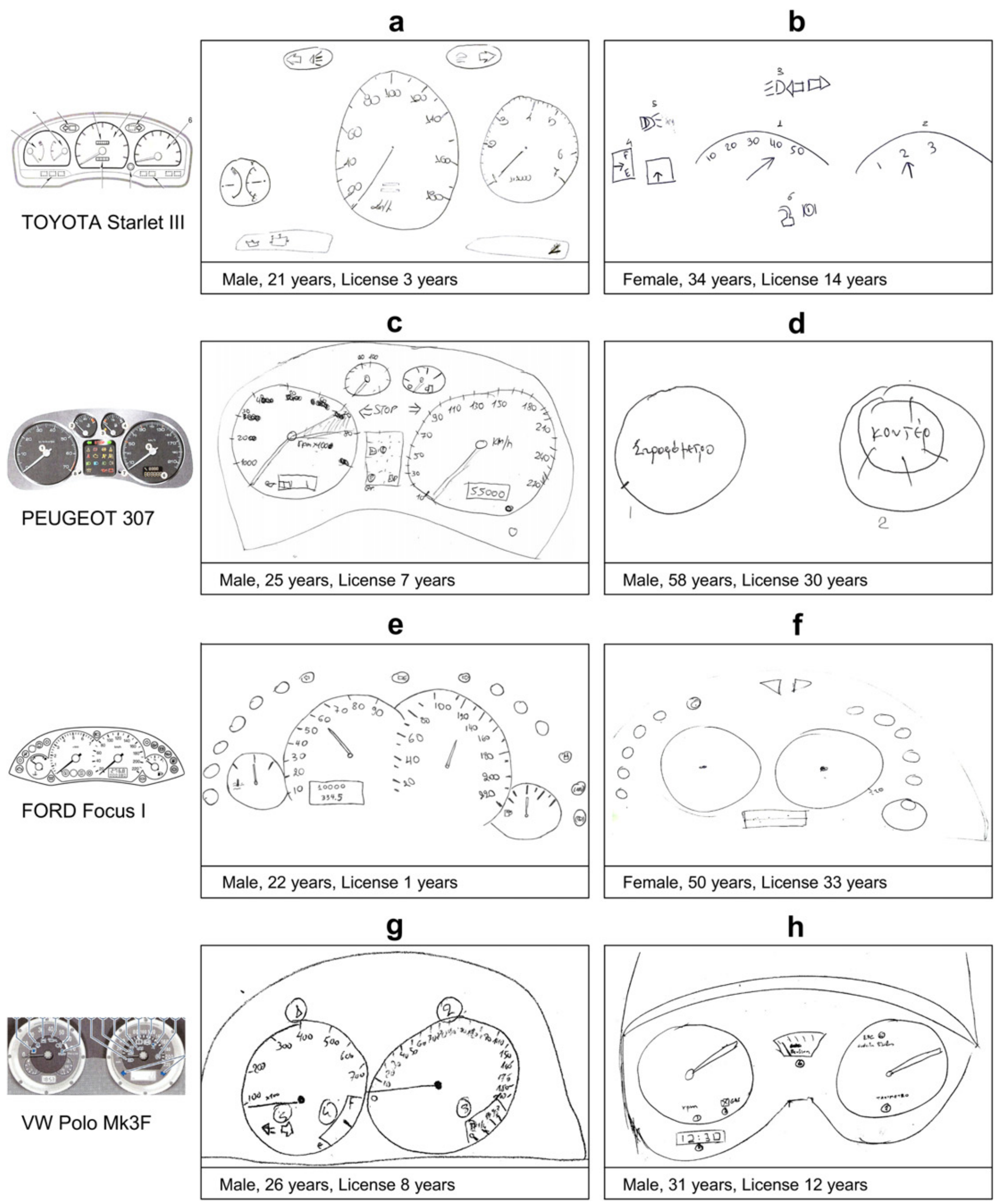


Fig. 1. Examples of participants' drawings with different level of driving experience, and the corresponding picture of the actual display panel.

Table 4
Mean and standard deviation values of the scores for omitted display units per group of drivers [S: speedometer, R: RPM counter, F: fuel gauge, T: temperature gauge].

Groups of participants	N	Scores for omitted display units									
		S		R		F		T		Total	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A less experienced	114	1.0	(.00)	1.0	(.00)	.96	(.18)	.87	(.34)	.96	(.10)
B mid experienced	104	1.0	(.00)	1.0	(.00)	.95	(.22)	.91	(.29)	.97	(.11)
C experienced	117	1.0	(.00)	.99	(.09)	.92	(.27)	.79	(.41)	.93	(.15)
Sum	335	1.0	(.00)	1.0	(.06)	.95	(.23)	.85	(.35)	.95	(.12)

depict only the features they consider significant, while the less experienced drivers depict as many features as possible.

4.2. Omitted display units

Table 4 presents the mean and the standard deviation values of the partial and total scores for the omitted display units, per group of drivers.

The data were analyzed using one-way ANOVA for unrelated samples, with driving experience (groups: A, B and C) as the independent variable. Concerning the total scores, the analysis showed significant difference among the three groups of drivers ($F = 3.893$, $p < .021$, significance level .05). Two-sample *t*-tests were then carried out. These tests showed significant difference between the groups A and C ($t = 2.163$, $p < .033$), as well as between the groups B and C ($t = 2.516$, $p < .013$) and no significant difference between the groups A and B ($t = -.034$, $p < .973$). Therefore, it can be concluded that the drawn display panels of the experienced drivers (>12 years) were more “laconic” than the less experienced ones. Considering the scores for each display unit, it can be noticed that the more frequently omitted one was the temperature gauge.

Finally, the possible effect of the type of display units’ layout to the number of omitted display units was also examined. The data were analyzed by using one-way ANOVA for unrelated samples, with the type of display units’ layout as the independent variable. No significant difference was found ($F = 2.321$, $p < .075$, significance level .05).

4.3. Accuracy of the arrangement of drawn display units

The deformations of the drawings produced by the drivers were also examined in terms of the accuracy of the arrangement of the main display units, as a function of driving experience. Table 5 presents the mean and the standard deviation values of the partial and the overall scores for the arrangement of the drawn display units, per group of drivers. As stated in Section 3.3, score 1 was attributed when there was no re-arrangement.

The data were analyzed using one-way ANOVA for unrelated samples, with driving experience (groups: A, B and C) as the independent variable. Concerning the total scores, no significant difference was found ($F = 1.028$, $p < .359$, significance level .05).

In addition, the possible effect of the type of display units’ layout to the arrangement of the drawn display units was also examined. The data were analyzed by using one-way ANOVA for unrelated samples, with the type of display units’ layout as the independent variable. No significant difference was found ($F = 1.161$, $p < .075$, significance level .05).

4.4. Accuracy of numbering/labeling the drawn display units

Table 6 presents the mean and the standard deviation values of the partial and total scores for the numbering/labeling of the drawn display units, per group of drivers.

The data were analyzed using one-way ANOVA for unrelated samples, with driving experience (groups: A, B and C) as the independent variable. Concerning the total scores, the analysis showed significant difference among the three groups of drivers ($F = 7.157$, $p < .001$, significance level .05). Carrying out two-sample *t*-tests, significant differences were found between the groups A and C ($t = 3.259$, $p < .001$), as well as between the groups B and C ($t = 3.254$, $p < .001$), but no significant difference between the groups A and B ($t = -.071$, $p < .943$).

As far as the scores for each display unit, the analysis showed significant difference regarding numbering/labeling of “S” ($F = 3.521$, $p < .031$), “F” ($F = 7.822$, $p < .000$), and “T” ($F = 2.972$, $p < .049$). No significant difference was found for numbering/labeling of “R” ($F = 1.661$, $p < .192$). Carrying out two-sample *t*-tests, significant differences were found:

- Between groups A and C ($t = 2.228$, $p < .028$), as well as between groups B and C ($t = 2.841$, $p < .005$) for the scores regarding the numbering/labeling of “S”
- Between the groups A and C ($t = 3.483$, $p < .001$), as well as between the groups B and C ($t = 2.603$, $p < .011$) for the scores regarding the numbering/labeling of “F”
- Between the groups A and C ($t = 2.356$, $p < .021$) for the scores regarding the numbering/labeling of “T”.

Consequently, it seems that the operative image-reference of experienced drivers contains fewer details regarding the numbering/labeling of the display units, and this stands for all the display units.

Table 5
Mean and standard deviation values of the scores attributed to the drawings regarding the accuracy of the relative arrangement of drawn display units [S: speedometer, R: RPM counter, F: fuel gauge, T: temperature gauge].

Groups of participants	N	Scores for the accuracy of the relative arrangement of display units									
		S		R		F		T		Total	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A less experienced	114	.85	(.36)	.85	(.36)	.79	(.41)	.83	(.38)	.82	(.31)
B mid experienced	104	.93	(.25)	.92	(.27)	.83	(.38)	.84	(.37)	.88	(.24)
C experienced	117	.88	(.33)	.87	(.34)	.79	(.41)	.82	(.39)	.84	(.29)
Sum	335	.89	(.32)	.88	(.33)	.80	(.40)	.83	(.38)	.85	(.28)

Table 6
Mean and standard deviation values of the scores regarding accuracy of numbering/labeling the drawn display units [S: speedometer, R: RPM counter, F: fuel gauge, T: temperature gauge].

Groups of participants	*N*	Accuracy of numbering/labeling the display units									
		S		R		F		T		Total	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A less experienced	114	.52	(.22)	.41	(.22)	.62	(.25)	.47	(.36)	.51	(.19)
B mid experienced	104	.53	(.19)	.44	(.17)	.58	(.26)	.48	(.32)	.51	(.16)
C experienced	117	.46	(.25)	.38	(.21)	.49	(.27)	.38	(.31)	.43	(.20)
Sum	335	.50	(.22)	.41	(.20)	.56	(.27)	.44	(.33)	.48	(.19)

5. Discussion and conclusions

The main results of the present study could be summarized as follows:

i. The drawings of experienced drivers are characterized by more deformations compared to those of less experienced ones. Specifically, the experienced drivers' drawings are more "distant" from the actual display panels, in terms of general resemblance, while the less experienced drivers tend to depict the display panel closer to the actual one.
ii. The drawings of experienced drivers are characterized by laconism. Specifically, the experienced drivers depict fewer display units than the less experienced ones, while specific elements of them (e.g. numbering and labeling of the drawn display units) are either omitted or drastically simplified.
iii. The observed deformations in the drawings of experienced drivers are not random but concern specific elements or features of the display panel. The more frequent deformations are: omission of the temperature gauge, omission or erroneous depiction of the scale range and pictorial material of the fuel and the temperature gauges, as well as of the scale intervals of the speedometer and RPM counter. On the contrary, the arrangement of the drawn display units remains unchanged in comparison to the actual display panel.
iv. Finally, the four types of display units' layouts that were identified in this study do not affect the participants' drawings in terms of any of the criteria used to assess their resemblance to the actual display panel.

The above results are in agreement with the concept of the operative image-reference, and accordingly, with the two working hypotheses on which the present study has been based. Specifically, we can conclude that the experienced drivers' drawings were guided by the OI-R they formed for the display panels – providing therefore traces of the content of their OI-R, while the less experienced drivers, not disposing such an OI-R, produced drawings closer to the actual display panel of their own vehicle. Therefore, we can be informed for the relative importance the experienced drivers attribute to the information emitted by the various displays of the panel.

Since the experienced drivers in this study were also more aged, the omission of visual details or even of certain display units in the experienced drivers' drawings could be attributed to memory retrieval problems, i.e. to their deteriorated ability to retrieve from memory spatial location and numeric information (Chalfonte and Johnson, 1996; Glisky et al., 2001; Moulin and Gathercole, 2008). However, if this was the case, then it would be expected that the tendency of experienced drivers to depict fewer display units and fewer visual details, would equally apply to all display units and all visual details of them. Instead, as it was shown, the display unit that experienced drivers tended to omit more often was the temperature gauge, whereas, the visual details omitted more often at each display unit were not random. The above suggest that the observed deformations cannot be attributed to age-related retrieval failures.

At a theoretical level, the results of our study clearly support the usefulness of the concept of operative image-reference in the context of user-centered design. In fact, the front-end phases of the user-centered design aim to identify the content of the mental representations that experienced operators develop for task-relevant artefacts, as well as their relative importance for the accomplishment of particular tasks. Therefore, the operative image-reference concept provides an appropriate conceptual tool to this end, as it highlights the information that has functional significance for experienced operators.

At a methodological level, the present study provides evidence that the drawing method is appropriate for identifying traces of the operative images that experienced operators have developed. Compared to other widely used methods (e.g. questionnaire surveys or think-aloud method), a main advantage of the drawing method is related to its information richness, as well as that there is no need for describing the content of the memory through verbalization. Furthermore, drawings reflect not only the objects of the task environment that experienced operators tend to consider significant for the task accomplishment, but also the specific features of these objects. For example, as it was shown, experienced drivers not only tend to ignore more often the temperature gauge than the fuel one, but also they tend to ignore more often the visual details of the former even if it contains fewer visual details than the later one.

Finally, at a practical level, the results of the present study trace directions for a simplification of the future display panels. In fact, as it was stated in the introduction, there is a need to design leaner display panels, because of the potential hazardous effects in terms of driver distraction/workload that arises from the ever-growing number of new driver support systems that are introduced in modern vehicles. Specifically, considering the traces of the operative images-references of experienced drivers, future designs of display panels might take the following directions:

– Alleviate the appearance of the temperature gauge, or even replace it with a tell-tale light, invisible to the driver when engine temperature is normal,
– Simplify the numbering/labeling of the speedometer, the RPM counter and the fuel gauge, e.g. by showing only critical number intervals or by color coding critical areas.

Such modifications of the appearance of the display units are expected to have no adverse side-effects for the drivers, as these features of the actual display panels seem to have slight importance for the drivers. Furthermore, according to the results of the present study, the re-arrangement of the four examined display units is expected to have no adverse side-effects for the drivers.

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