Human-Vehicle Interaction to Support Driver's Situation Awareness in Automated Vehicles: a Systematic Review

Marine Capallera, Leonardo Angelini, Quentin Meteier, Omar Abou Khaled, Elena Mugellini

***Abstract*—Autonomous driving will change the role of the driver. From being the main actor in driving, the driver will now have a supervisory role during the autonomous driving phases. However, if the driver has to take over control of the vehicle, he must be aware of the situation around him. This is why it is important to develop interfaces to keep him in the loop. This article proposes a systematic review of Human Vehicle Interaction (HVI) providing situation awareness in the context of autonomous driving. 37 articles presenting such interactions are analyzed in terms of design of the interaction (modalities, location, conveyed information) but also in term of evaluation and experimental conditions. We present an overview of previous studies in order to highlight the work already done or in progress. Current studies present mainly monomodal interfaces although the evaluation of multimodal interactions present promising results in this field.**

***Index Terms*—automated driving, Human-Vehicle Interaction (HVI), peripheral interaction, systematic review, Situation Awareness (SA)**

I. Introduction

Designing and evaluating interfaces to support Situation Awareness (SA) in automated vehicles is a challenging and is still an open research domain. Currently, many studies have been conducted to assess different interfaces for increasing SA in automated vehicles, however, there is a lack of a comprehensive overview of the research paths explored and the results obtained so far. Salmon et al. [1] observe that research related to SA in the automotive field is still quite rare but that it is important to consider this aspect and its impact on road safety. In order to overcome this lack, we conducted a systematic review where we investigate how Human-Vehicle Interfaces (HVI) were designed and evaluated and which designs were proven to be effective in previous studies. This article could facilitate the search for existing work, as well as the search for new research pathways, getting a better understanding of the existing results from previous studies and a glance on the research gaps that should be filled. Therefore, the main contribution of this review to the automotive field is to provide an overview of current research on interface development and interaction design to maintain and/or increase driver SA in high levels of automation. The expected impact of this systematic review is to inspire and speed up novel research studies for the design and evaluation of new interactions to maintain driver SA during autonomous phases. Thanks to this review, researchers and industries should be able to easily compare their results with previous findings, building new pieces of knowledge for this promising research field (see section Motivation and Objectives for more details). The rest of this section describes briefly the general context of autonomous driving, provides insights of situation awareness in this context. The last two subsections provide details under on the attention/interaction continuum.

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A. Driving automation

The Society of Automotive Engineers International (SAE) [2] proposes a vehicle classification from level 0 (no automation) to Level 5 SAE (fully automated). Partially automated vehicles (Level 2 SAE) are currently on the market and have been on the road for several years now. These systemsare used under very precise driving conditions and under constant supervision of the driver. Level 3 SAE (conditionally automated driving) does not require driver supervision. However, the driver must be able to regain control of the vehicle at the request of the system, which could occur at any time. Thus, this type of vehicles tends more and more to modify the role of the drivers, from being an active actor of the driving task, to a supervisor who can engage in other types of tasks.

Nevertheless, in conditionally automated driving, since drivers are allowed to perform a non-driving-related task (NDRT) during the autonomous driving phase, a takeover request (TOR) could result in a sudden peak of cognitive workload for the driver and thus lead to potentially dangerous situations [3].

At the same time, monotonous tasks such as monitoring the road during autonomous driving can lead to driver drowsiness [4], which can also lead to dangerous situations. Moreover, several studies have shown that mental workload and situational awareness decrease with increasing levels of automation. Similarly, drivers' reaction time increases during autonomous driving [5]–[7]. The higher the level of automation, the more time drivers need to perceive and understand the situation; furthermore, shorter warning times correspond to reduced recovery quality [8]–[10]. Therefore, it is important to keep drivers "in-the-loop" and support them in their supervision task.

When developing such automated vehicles, it is important to design interactions able to maintain the situational awareness

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of the drivers during the autonomous driving phases and able to accompany the drivers on effective control recoveries. As drivers are not expected to focus on the supervision task, interfaces for enhancing the situational awareness should require only the peripheral attention of the user.

B. Situation Awareness and autonomous vehicle

The most commonly used definition for situation awareness is: *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* [11]. It can be represented thanks to different models such as the cognitive subsystems approach of Bedney and Meister [12], the perceptual cycle model of Smith and Hancock [13] or the three-level models of Endsley. The latter is most often used in the literature. This model is divided into three levels [11]:

- Level 1 - Perception of the elements in the environment
- Level 2 - Comprehension of the current situation
- Level 3 - Projection of future status

Endsley's model was first developed for the aviation field but is also used in the military and nuclear fields [14]–[16]. A theoretical model of driver situational awareness (SA) was also proposed. [17]. Indeed, the driver must maintain knowledge about navigation, environment and interaction, spatial orientation and vehicle status. Bolstad et al. [17] define the factors that can influence it, such as the characteristics and limitations of the driver, as well as the technologies that increasingly automate vehicles.
Because acquiring and maintaining SA is important, it is essential to be able to assess it. Thanh Nguyen et al. [18] propose a review of Situation Awareness assessment approaches and classify them into 6 techniques: freeze-probes, real-time probe, post-trial self-rating, observer rating, performance measures and process indices.
According to previous literature and Thanh Nguyen et al., the most frequently used techniques are the freeze-probes techniques with SAGAT questionnaire (Situation Awareness Global Assessment Technique) [19] and the post-trial self-rating with the SART questionnaire (Situation Awareness Rating Technique) [20].

C. Attention/interaction continuum

As mentioned above, it is important for drivers to acquire and maintain a sufficient level of SA even in automated driving phases so that they can be able to regain control of the vehicle when prompted. Thus, it is necessary to keep them in the control loop conveying context-related information and vehicle status while they are possibly engaging in other NDRTs. As drivers should be able to continuously switch the focus of attention, from non-driving related tasks to supervision, eventually taking over control, Human-Vehicle Interfaces should be designed considering the full Interaction-Attention Continuum. This concept, introduced by Bakker and Niemantsverdriet [21] propose a scale of attention and interaction levels going from implicit, to peripheral and focused interactions.

- **Focused interaction**: it is the most common interaction type. It requires focused attention and it's difficult to perform another activity in parallel.
  e.g.: enter address in GPS, manual driving...
- **Peripheral interaction**: it aims to "present information from computing systems to users in a subtle manner, such that it can be perceived in their periphery of attention". It also includes ambient information displays, peripheral displays and awareness systems.
  e.g.: discuss with passengers, change music using steering wheel buttons, hand free kit, ...
- **Implicit interaction**: "rely on automatic sensing of people's activity or presence as input for computer-initiated activities". It is illustrated by ambient intelligence, internet of things, ubiquitous sensor...
  e.g.: auto light - auto windshield wipers...

The principle of peripheral interaction allows us to design and implement different interfaces that can exploit this level of attention in order to maintain the SA while the user is performing other tasks. However, it is necessary to take into account appropriate design rules.

The rest of the article is structured as follows: the next section describes the motivation and the objectives of this survey. The methodology used to conduct this study is then detailed, followed by the results of the analysis conducted during this review. Finally, we discuss these results in the last section of this paper.

II. Motivation and Objectives

Many studies on situational awareness have already been conducted in the highly automated aviation domain [22]–[24]. Many experimental studies have been conducted in the automotive field to evaluate drivers' SA. However, there are few systematic reviews comparing them. Salmon et al. [1] show that research related to SA in the automotive field is still quite rare but that it is important to consider this aspect, which can have an impact on road safety. Moreover, most of the techniques for measuring SA require stopping the simulation, making SA sometimes difficult to evaluate. It would be interesting to see if there are new interactions to measure the SA of the driver.

The motivation of this review is to provide an overview of current research on the development of interfaces and the design of interactions for maintaining and/or increasing the driver's SA in high levels of automation. This overview would allow us and other researchers and industries to highlight current practices and to identify guidelines for the design and evaluation of new interactions aimed at maintaining driver awareness during autonomous phases.

This review is focused on vehicles with automation levels ranging from 3 to 5. Indeed, for conditionally and highly automated vehicles (level 3 and 4), the driver may have to take control of the vehicle depending on the situation. This is why it is important to keep the driver aware of his/her environment and to support him/her in an efficient and safe takeover. Even if fully-autonomous vehicles (level 5) do not need a driver, the awareness of the environment and the behavior of the car is considered as a confidence factor towards the system (also valid for the lower levels). It is therefore important to maintain the situation awareness in order to increase the trust of drivers towards these vehicles [25].

The goal of this review is to answer the following research questions:

RQ1. How Human-Vehicle Interfaces (HVI) can be designed and how they can be operated at different levels of attention to support supervision and situational awareness? The first objective is to identify

- **what type of information to send**,
- **how**: peripheral, focused, implicit, ...
- **with which modality(ies)**: visual, audio-visual, haptic, multi-sensory...
- and **where**: exploiting the different parts of the car such as steering wheel, windshield, screens, seat, ...

We wanted also to analyze whether these elements vary according to the situation (hazardous or not), the state of the driver (is he performing a non-driving related task), in order to improve or maintain the driver's SA.

RQ2. How Human-Vehicle Interfaces (HVI) supporting driver's supervision are evaluated? The second objective of this review is to analyze how the different interfaces are evaluated in the previous studies. This includes the driving scenarios, variables to be measured and measurement methods.

RQ3. How interfaces for measuring driver's SA can be designed and evaluated? The third objective is to analyze the different interfaces specifically developed to assess driver's situation awareness and how these are evaluated.

III. Review Methodology

The review follows the PRISMA methodology [26]. This section describes the literature search, the screening and the eligibility steps. Then, the section details the analysis and meta-review criteria of the study.

A. Literature Search and Identification

In order to make a state of the art of all systems that increase the situational awareness of the driver during automated driving, a review of the literature was performed following a systematic process. The analysis of the previous studies should allow us to better understand the issue of the involvement of the autonomous system as a companion of the driver and the way to share control and responsibilities.

The databases searched were ACM Digital Library, ScienceDirect, IEEE, Scopus, PubMed, and Web of Science with Conference Proceedings. We selected only conference papers, journal articles, or one article in a book (a chapter or the full book are excluded) from 2012 to April 2020. 2012 corresponds to the appearance of level 2 vehicles on the market and the beginning of research in situation awareness in vehicles with higher levels of automation. In addition, the SAE standard on the levels of automated driving date from 2016 [27] (revisions have been made since then). 74 articles were also included from additional sources for their particular relevance with the research questions. These external resources came from our previous research on the domain or could were extracted from the bibliography of the pool of articles collected with the systematic queries.

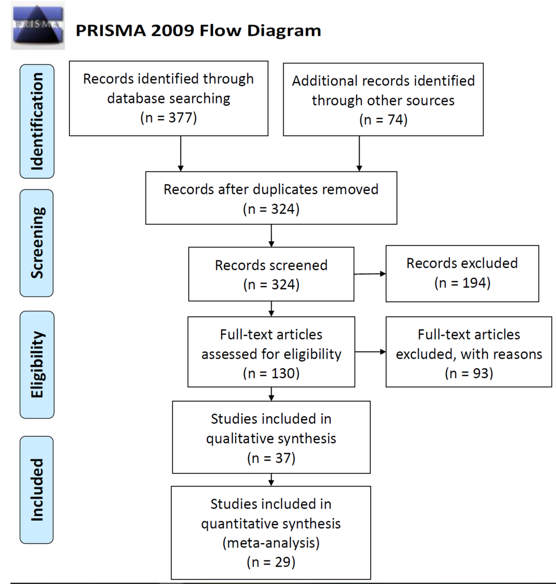

Fig. 1. PRISMA Diagram

The keywords used in the queries focus on situation awareness into semi-autonomous vehicles. Queries were adapted to the different databases, in particular in terms of syntax and number of terms. Three groups of keywords were identified:

- In order to select articles having for main topic the driver's situation awareness: SA, situation* awareness, loop, alert*, driver attention, peripheral attention, peripheral interaction,
- In order to select articles from the automotive domain and focusing on semi-autonomous driving: car*, vehicle*, driver, automobile, automated, autonomous, highly automated, ADAS, semi-autonomous,
- In order to gather articles presenting human-machine interaction and interfaces, but also articles proposing method to evaluate driver's situation awareness: measur*, hmi, human machine, user centered, human computer, human factors.

All the queries for the different databases are available in Appendix A. We started the analysis with a pool of 451 articles. The PRISMA diagram (Figure 1) summarizes the steps of the screening and analysis process. The methodology for each step is detailed in the following sections.

B. First screening

After removing duplicates, reviewers screened 324 articles in pairs. The purpose of this phase is to remove off-topic and non-relevant documents by reading only titles and abstracts. For the first screening, the exclusion criteria were unavailable full-text, book and press articles, non-English written papers, and paper not relevant to the automotive field or the topic in general. Articles focusing only on take-over request were also excluded. At the end of the screening phase, reviewers retained 130 articles.

C. Eligibility

In order to refine the search and to be able to analyze the relevant studies that meet the search strategy of this review, we have detailed and specified the characteristics that the studies must have through eligibility criteria. The eligibility criteria to select papers relevant for our database are the following:

- The paper presents an HMI maintaining driver's Situation Awareness (notify the driver about his/her environment or about the vehicle "state" and decisions)
- or presents an HMI measuring situation awareness (not psychophysiological data and signal processing)
- The paper presents a driving scenario (simulator or real driving) and provides experiment results about automated driving (lvl 3 or more).
- *Optional 1*: the paper proposes a definition of SA in the automotive domain
- *Optional 2*: the paper describes a concept of HMI increasing SA (with no experiment could be kept; even if the scenario was performed in manual driving. Reviewers could keep papers presenting relevant concepts)
- **Excluded**: Articles focusing only on Take-Over Request and studies presenting the effects of automated driving on driver behavior

Three reviewers screened the 130 full text articles independently to evaluate the eligibility of each article. Disagreement was resolved by discussion. At this point, 38 eligible papers composed the pool of articles.

Two papers present the same situation awareness evaluation interface [28] and [29]. One is a short paper and the other is a more complete article. Therefore, in the following sections, they will be counted as one article.

As a further exception that is worth noting, although the authors of [30] considered their study as pertaining to partially autonomous vehicles (level 2), participant were required to perform a secondary task. Therefore, we consider this article in level 3 automation context.

Thus, the distribution of articles is as follows:

- 37 articles about HMI increasing situation awareness, with 30 articles presenting an experiment with results and 7 papers presenting a concept or proof of concept with promising results for some of them.
- including 1 article about HMI measuring situation awareness.

Figure 2 shows the distribution of the eligible articles through years. We can note that the majority of the research presented in this analysis was carried out on the years 2015, 2016, 2017 and 2019.

D. Analysis and classification

After the eligibility phase, reviewers conducted a quantitative analysis on the 37 papers (see Figure 1). In this step, reviewers analyzed and classified the different concepts and interfaces presented according to the different criteria presented in the following sub-sections. All articles were analyzed by reviewers separately. The results of the reviewers were then compared. If there were differences, the points were discussed until both parties agreed. This analysis mainly described the aim of the paper, collected information about the HMI (type of interaction, modality and location into the vehicle), the scenario (level of automation, condition and driving environment), and the experiment (conveyed information, measurements and results). All criteria were available to all reviewers in the form of drop-down lists described below. It is possible to select several items in the list and add other if not present in the list.

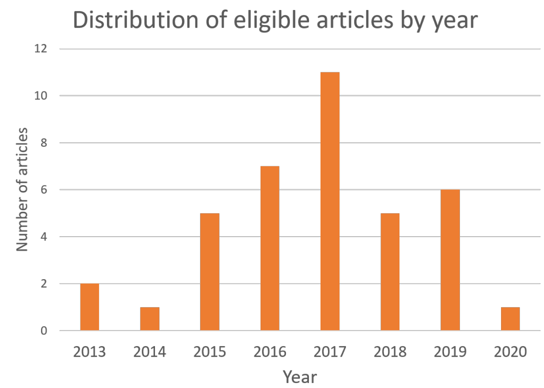

Fig. 2. Distribution of eligible articles by year

1) Interaction: The items allowing the classification of the modalities are the following. They are based on the five human senses excluding taste. We focus mainly on the output modality of the interface to inform the driver.

- Visual: light, text, icons and symbols, video
- Auditory: chime, speech, music
- Haptic: vibration, pressure
- Olfactory

2) Interaction Attention Continuum: Two reviewers performed first this analysis without discussion and then discussed with a third reviewer in case of conflict. We have added intermediate categories because some interactions do not take place at a single level of attention but move along the continuum. The criteria, expanded from Bakker [21] are the following:

- **Focused interaction**: requires focused attention. The user cannot perform another important task in parallel (for example, driving and texting).
- **Focused-Peripheral interaction**: operated at both levels of attention. The interaction shifts along the continuum from peripheral to focused attention (or from focused to peripheral)
- **Peripheral interaction:** perceived in the periphery attention - outside of the focus of attention: interactions apply to the peripheral field of view of the user or it is a brief action performed in parallel to other activities or to include both surrounding perception and surrounding interaction
- **Peripheral-Implicit interaction**: operated at both levels

of attention. The interaction shifts along the continuum (from peripheral to implicit interaction) or from implicit to peripheral

- **Implicit interaction:** does not require explicit commands from a user - systems that act autonomously based on sensor input (it is an autonomous system that is not designed to deliver explicit information to the user).
- **All continuum:** could operate at all levels of attention. The interaction shifts along all the continuum.

3) Location: For this analysis we considered the following definitions, inspired by Kern et al. in previous literature [31]. In their article, they define the following areas: windshield, dashboard (the left part directly in front of the driver), center stack (horizontal and vertical), floor, periphery (side and rear view mirrors), steering wheel (both front side and back side). For this analysis, we used definitions found in literature and we slightly adapted them:

- We call the area behind the steering defined by Kern et al. "dashboard B". The part under the entire windshield and above the vertical center stack is called "dashboard A" in our case.
- The "periphery" also includes the pillars of the vehicle
- We add the driver seat as an area of interaction.
- Some interactions are performed directly on the driver using wearable devices.
- "Steering wheel" represents the front side and not the back of the steering wheel.

All the locations are depicted in Figure 3.

4) Levels of automation: The items for the levels of automation were defined by the SAE taxonomy [27]. They range from level 3 to level 5 with the "unspecified" option.

5) Driving scenario: The items describing the setup used to perform the different experiments were "real-life", "fixed-based simulator", "motion-based simulator". When the driving equipment was not mentioned, an "unspecified" option was available.

6) Non-driving-related task: Naujoks et al. [32] proposes a review on non-driving related task used in studies in automated driving. In order to condense the information, we have grouped the NDRTs into several interaction categories. These modalities of NDRT are "Visual" (mainly reading, watching a video), "Visual and biomechanical" (mainly search task, texting), "Vocal" (chatting), "Unspecified" and "Multiple choice".

7) Conveyed information: The notifications are grouped according to the taxonomy of Capallera et al. [33]. The main categories mentioned in this article are the following:

- Environment: adverse weather, bright light, very hot/cold temperature
- External Human Factor: heavy traffic, pedestrians
- Road: Bumpy road, slopping road, intersections
- Lane: lane division uncleared or damaged, construction zone
- Obstacle: temporary obstacle, stopped car ahead, distance between vehicle too small
- Vehicle alteration: obstructed/damaged sensors, unauthorized modification

Because the taxonomy was obtained from the limitations reported by level 2 vehicle owners' manuals, the analysis and classification were slightly adapted for level 3 and more. Thus, in this review, we have extended this taxonomy by adding some elements. We added the two categories "Vehicle" and "Other". The elements *autonomous status, speed, vehicle's attention, uncertainty, confidence level, low fuel/tires pressure and driving data* were added to the new category called "Vehicle". The category "Other" is composed of the elements *traffic sign, hazards, TOR, cue, pre-alert, rear view and driving scene*.

8) Evaluation methods: In view of the wide variety of evaluation methods used in the different studies, the list of items was completed iteratively during the analysis phase. The elements are as follows. Situation Awareness is directly measured using SART [20], SAGAT [19] questionnaires. The mental workload to evaluate the impact of tested interfaces or the implication in the NDRT is assessed with, NASA-TLX (NASA Task Load Index) [34] or DALI (Driving Activity Load Index) [35]. Other situational data and physiological data, such as driving data (e.g. vehicle speed), TOR quality, reaction time, collision, deviation, crossing lane, eye-gaze, visual workload, driving behavior, task accuracy were also used to extrapolate driver's situation awareness and behavior when using the evaluated interface. Finally, more general aspects related to the user experience such as trust, acceptance, usefulness and open questionnaire were also an analyzed in respect to the evaluation of the proposed interfaces.

E. Meta-analysis

The authors also performed a meta-analysis of the results presented in the different articles. The purpose of this analysis is to highlight work proposing a detailed interface design and a complete evaluation of the interface with significant results. This part allows to go further than a general view of the developed concepts or innovation ideas. The role of this section is also to highlight the protocols, methods and assessment techniques used in the studies presented so that researchers wishing to conduct a similar study can set up a precise testing protocol and be able to compare their results with the existing literature.

The eligibility criteria for this analysis are as follows:

- the article describes an experiment and an evaluation protocol
- the article presents a statistical analysis of the study (p-value is reported)

Because study designs, number of participants, interaction modalities, and outcome measures vary considerably, we focused on a qualitative synthesis with descriptions of the studies, their results, applicability, and limitations.

A total of 29 articles were analyzed in this phase. The main criteria put forward were the presentation of results on the driver's awareness, behavior (quality of takeover, collisions, reaction time, etc...) and confidence in the tested system and on the system acceptance/usability.

IV. Results

The results of the analysis according to the criteria described above are presented in this section. The overall analysis included all 37 articles, whereas the meta-analysis was based on 29 studies. Some results are derived from the combined analysis of several criteria in order to discover possible links between items of different criteria (e.g. the type of modality and its location in the vehicle).

A. Overview of HVI to support supervision and situation awareness (RQ1)

1) Modality interaction and location: This part of the analysis provides an overview of the different interaction modalities and locations used by the interfaces (see Table I for a summary). Table I classifies the analyzed items according to the ***[interaction modalities]*** used by the interfaces as well as their ***[location]*** in the vehicle. In total, 27 articles present HVI using only one modality, i.e. 73% of the article corpus. The most used modality is the visual one, presented in 20 papers [28], [30], [36]–[53]. Four articles report the use of the auditory modality [47], [54]–[56] whereas three papers present HVI using haptic modality [57]–[59]. Only 11 articles propose multimodal HVI. The majority of them (82%) are audio-visual [60]–[68]. One paper [69] proposes a combination of haptic and visual modalities. Another paper [70] proposes a concept using haptic, auditory and visual modalities, where an agent travels in vehicle's interior surfaces (pillar, dashboard, windshield), providing haptic stimuli and using natural language to communicate with the driver.

Figure 3 illustrates which interaction areas are used by the different concepts presented in the analyzed articles. The colors represent how often the location is used through all the pool of articles. For example, we can see that the windshield is the most frequently location used to convey information (about 35%), followed by the center stack (about 30%). 11% of the articles use the part of the dashboard behind the steering wheel and 8% (three articles) the dashboard above. Also, three papers convey information directly on the driver's wrists or glasses. 5% of modalities are displayed on the lateral pillars, 5% use driver seat as interface. Finally, the steering wheel is used in few concepts (about 3%), moreover only one article proposes to use all the interior of the vehicle [70]. Articles [52], [65], [66] use both windshield and center stack whereas [39] displays light above the dashboard and icons on the center stack. No article uses the floor as interface.

2) Interaction Attention continuum: Figure 4 classifies the interactions using the interaction-attention continuum defined by Bakker [21]. During the analysis of the 37 articles, the authors were in total agreement for 22 articles and in total disagreement for three articles. 12 articles were classified in contiguous categories on the attention-interaction continuum. For example, one author classified article [64] as peripheral interaction while another defined the interaction on the peripheral-focused category. In total, 15 items were discussed until agreement. The final version is presented in Figure 4. To summarize, 25 papers (i.e. 68%) present interactions on ***peripheral*** attention, 12 papers propose interactions on the

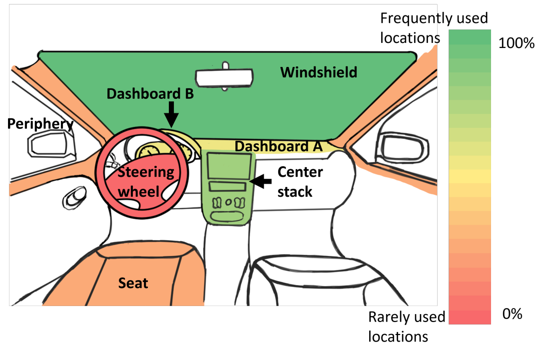

Fig. 3. Frequency of interaction's location - all modalities

peripheral-focused continuum and one paper proposes a concept of ***focused*** interaction. Finally, one research describes a concept that can act on the whole continuum.

3) Conveyed information: Table II summarizes all the information conveyed through all the interfaces presented in all articles. Three articles convey information about the "environment". Eight systems notify element from the "lane" category such as construction zones ([29], [47], [49]). 17 HVIs transmit information according to the "External Human Factor" category. There are mostly about heavy traffic ([29], [36], [43], [54], [64], [65]), the presence of other cars ([30], [39], [54], [57], [59], [62], [64]) or pedestrians around ([45], [47], [63]) the vehicle. 10 mention "obstacle" elements, in particular temporary obstacles ([30], [45], [64], [65], [68]). Six articles mention "road" elements. Then 30 convey information about the vehicle and more particularly concerning the status of the autonomous system ([30], [39], [41], [44], [52], [60], [61], [66], [70]), vehicle intention ([36], [37], [42], [43], [46], [48], [49], [58], [63]) or uncertainty ([30], [50], [69]). Finally, and 25 interactions are classified in the "other" category. They mainly notify hazards ([29], [36], [43], [44], [48], [51]), pre-alert ([44], [62], [65], [70]) and takeover request ([30], [36], [44], [65], [67]).

B. Evaluation of HVI to support supervision and situation awareness (RQ2)

The second part of our analysis synthesizes how the different interfaces are evaluated in the selected articles and provides an overview of the experimental designs. This part of the analysis was only done on the 30 articles presenting an experiment. The seven articles presenting only a concept, as well as the article presenting an interface to evaluate the situation awareness, were not considered in this part.

1) Experimental setup and demographic composition: This paragraph gives an overview of the setup used to perform the different experiments. 30 articles present the realization of an experiment to evaluate their concept. Two experiments were performed in a real car [43], [58]. The autonomous driving conditions were set up using the Wizard of Oz method. Two experiments were carried out using a motion-based simulator [61], [68]. 24 articles (65% of the corpus) describe the use of a fixed-based simulator ([30], [36]–[41], [44], [49], [50], [52]–[55], [57], [59], [60], [62], [64]–[67], [69]). One

TABLE I
MODALITIES AND LOCATION.

			windshield and/or HUD	**dashboard (A)**	**dashboard (B)**	**center stack (vertical)**	**steering wheel**	**periphery (pillar)**	**seat**	**driver**	**all interior (sound)**
Mono-modalities	Visual	light	[36], [40]	[38], [39]	[48]	[37]	[41]	[37], [42]		[43]	
		text	[30], [45]–[47]			[29], [44]					
		icons	[30], [51], [52], [45], [46]		[48], [50]	[29], [39], [44], [49]					
		video				[52], [53]					
	Auditory	chime									[47], [54], [55]
		speech									[47], [56]
	Haptic	vibration							[59]	[57], [58]	
Multi-modalities	Audio-visual	Chime and/or speech + icons and/or text	[61], [66], [68], [62], [65]	[65]	[64]	[60], [67]					[61], [66], [68], [60], [62], [64] [65]
		speech, chime, icon, light, physical movement		[63]							
		video				[66]					
	Haptic and visual	vibration, icons and light			[69] icon	[69] icon		[69] light	[69] vibration		
	Visual, auditory and haptic	icon/text, vibration and chime									[70]

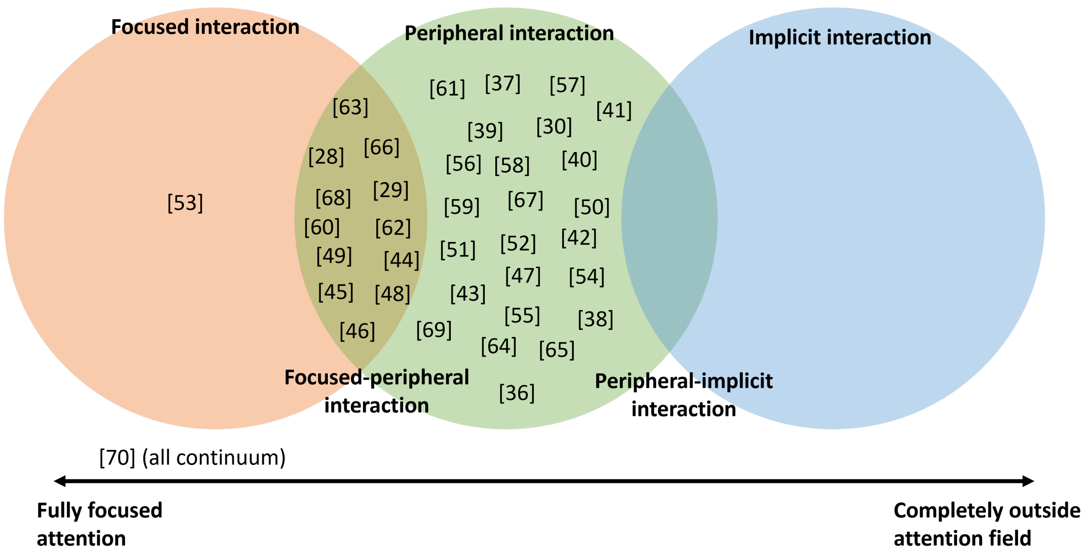

Fig. 4. Classification of interaction using the continuum adapted from [21]

article [42] do not mention any information about its setup. The demographic composition of the 29 articles describing an experimental study with reported results was also observed. Across all studies, the mean number of participants was 33.41 with a standard deviation of 21.31. To cite extreme values, [37] reported results from six participants while [66] conducted a study with 90 participants. 23 studies report the age of the participants (mean or range) as well as their gender. Taking into account the averages reported by 20 articles, the average age of the participants is 29.77 years old (SD = 7368). Of all the articles reporting a range, the ages vary from 18 to 75 years. On average 14.74 women (SD = 10.64) participated in the experiments compared to 20.29 (SD = 10.03) men However, the impact of these data is not included in the analyses of the studies.

2) Non-Driving Related task: 22 articles include the completion of a non-driving related task during their experiment. Most of the tasks performed by test subjects are visual (such as reading [43], [64], [67], [68], visual search task [30], [47], [49], [50], [52], [65], [69], watching video [42]), auditory (listen to music), visual and biomechanical [37], [38] (searching based menu [66], texting [44], [59], searching target [36]) or oral (chatting). In two articles [45], [60], participants were able to choose the task they would like to perform during automotive driving among, for example, using their phone, PC or tablet, reading a book, sleeping, monitoring the roadway, listening to the radio, eating a snack or doing cosmetics. In two cases, NDRT are not specified [53], [58].

In order to understand if an interaction modality is more effective in increasing the situation awareness during a specific NDRT, among the articles cited above we have extracted those with significant results in terms of situation awareness. Indeed, the aim of this work is to identify whether the modality of the interaction could depend on the type of non-driving-related task. Thus, among the articles cited above, we have extracted those with significant results in terms of situation awareness in order to relate the modality and the location of the interaction allowing to maintain SA and the type of non-driving related task (see Part D - Meta-analysis overview). The results are summarized in Table III.

TABLE II
INFORMATION CONVEYED

Environment	3	bad visibility	**1 visual: icon + text on windshield [45]**
		adverse weather	**1 visual: light on windshield [36]**
			1 visual or auditory: text on windshield or earcons [47]
Lane	8	Construction zone	**1 visual or auditory: text on windshield or earcons [47]**
			2 visual: icons on center stack [49], icons and text on center stack [29]
		Intersection/Cross traffic	**1 visual: physical movement of avatar head on dashboard A [63]**
			1 auditory: chime [54]
		Lane markings damaged	**1 audio-visual: icons on windshield + chime [61]**
		Within city	**2 visual: icons on windshield [49], (school zone) icons and text on center stack [29]**
External Human Factor	17	Another car cuts in front	**1 auditory: chime [54]**
		Heavy traffic	**3 visual: light on windshield [36], light on driver's glasses [43],icons and text on center stack [29]**
			2 audio-visual: icons on dashboard + earcons [54], chime + AR on windshield and dashboard [65]
			1 auditory: chime [64]
		Pedestrians around the car	**1 audio-visual: icons on windshield + chime [45]**
			1 visual: icon and movement of avatar [63]
			1 visual or auditory: text on windshield or earcons [47]
		other cars	**2 audio-visual: icons on windshield + chime [62], icons on dashboard + earcons [54]**
			2 visual: icons and light on center stack and dashboard [39], icons and text AR on windshield [30]
			2 haptic: vibration on driver's wrists [57], vibration in driver's seat [59]
			1 auditory: chime [64]
Obstacles	10	Distance between vehicles too small	**1 audio-visual: chime + icons and text on center stack [67]**
			1 visual : icons on windshield and video on center stack [52]
		Motorbikes/Bicycles	**1 haptic: vibration on driver's wrists [57]**
		Stopped/Slow car ahead	**1 haptic: vibration on driver's wrists [57]**
			1 visual or auditory: text on windshield or earcons [30]
		Temporary obstacles	**2 visual: icon + text on windshield [45], icons and text AR on windshield [30]**
			3 audio-visual: icons on dashboard + earcons [64], chime + AR on windshield and dashboard [65], chime + additional speech+ icons and text (windshield) [68]
Road	6	Intersection/Cross traffic	**1 visual: icon on center stack [49]**
		Narrow/winding road	**1 visual: light on center stack [39]**
		Oncoming traffic	**2 visual: icons and light on windshield [45], icons on center stack [49]**
		Sloping road	**1 visual: icons on center stack [49]**
		Within city	**1 visual: icons on center stack [49]**
Vehicle	30	Sensors obstructed/damaged	**1 audio-visual: icons and text on center stack + chime [60]**
			1 visual: light on avatar [63]
		autonomous status	**10 visual: text on center stack [60], icons on center stack x3 [39], [44], [70], text on windshield (HUD) [30], icon on windshield (HUD)x3 [52], [61], [66], light on steering wheel or shape-changing steering wheel [41]**
		speed	**2 visual: icons and text on center stack [44], icons and text AR on windshield [30]**
		vehicle intention	**8 visual: light on windshield [36], light on periphery [37], [43], physical movement [63], driver's wrists [58], icons and text (dashboard) [48], icon on center stack [49], icon and text AR on windshield [46], light on periphery x2 (TV frame [42] and glasses [43])**
			1 haptic: vibration driver's seat [59]
		uncertainty	**1 visual + haptic: light on center stack + vibration in driver's seat and animated icons on dashboard [69]**
			2 visual: icon on HUD (bar vs. triangle) [30], icon on dashboard [50]
		car confidence lvl	**2 visual : icon and text on windshield [45], light dashboard [38]**
		low fuel /tire pressure	**1 audio or visual : text on windshield or earcons [47]**
		driving data	**1 auditory: chime [55]**
Other	25	traffic sign	**2 visual: icon and text on dashboard [48], icons and text AR on windshield [30]**
		hazards	**6 visual: icons on center stack [44], light windshield [36], text and icon on dashboard [48], icons on windshield (AR) [45], [51], light driver's glasses [43], icons and text on center stack [29]**
			1 audio-visual: chime + icons (center stack, windshield - VR) [65]
			2 auditory: speech [56], chime [47]
			1 visual or auditory: text on windshield or earcons [47]
		TOR	**3 auditory: speech x2 [44], [67], chime [65]**
			1 audio-visual: light (dashboard above) + icon on dashboard + chime [36]
			1 visual: icon on windshield (red bar) [30]
		cues	**1 visual: icon and text on windshield [44]**
			1 audio-visual-haptic: light, icons and text, speech [70]
		pre-alert	**1 visual: icon and text on windshield [44]**
			1 audio-visual-haptic: light, icons and text, speech [70]
			2 audio-visual: icons on windshield and chime [62], icon and text AR on windshield and dashboard [45], [65]
		rear view	**1 visual:** video center stack [66]
		driving scene	**1 visual:** video center stack [53]

TABLE III
HUMAN VEHICLE INTERACTION (HVI) MODALITIES (HORIZONTAL) RELATED TO NON DRIVING RELATED TASK (NDRT) TYPE (VERTICAL). ITALIC TEXT ARE ARTICLES THAT DO NOT PRESENT SIGNIFICANT RESULTS IN TERMS OF SA

HVI modality NDRT	Visual	Haptic	Visual + Auditory	Visual + Haptic
Visual	light on periphery [42], [43] *on dashboard [38]*		*1 chime + icon on dashboard [64], on center stack [67]*	vibration (driver seat) + icons (center stack), light (periphery) [69]
	icon + text windshield (AR) [30]			
	icons on center stack [49], dashboard [50]		1 chime + icons (center stack, windshield - VR) [65]	
	icon on windshield + video on center stack [52], [66]		*chime, additional speech, icons and text (windshield) [68]*	
	text on windshield [47]			
Visual and Biomechanical	light windshield [36]	vibration seat [59]		
	light on periphery [37]			
	text and icons on center stack [44]			
unspecified or multiple choice (*)	1 icon windshield (AR) + text center stack (*) [45]	vibration wrist [58]	chime + icons and text on center stack (*) [60]	
	1 rear view dashboard [53]			

3) Evaluation methods: This section focuses on the evaluation methods used and presented in the different articles. 11 articles directly evaluate ***SA*** with the methods mentioned in the introduction. Six articles ([45], [46], [52], [54], [66], [67]) use the freeze-probe SAGAT questionnaire while five articles [42], [53], [58], [60], [67] assess situation awareness using the SART questionnaire. The article [43] presents their own evaluation method called "DAZE", which is discussed in the next subsection. [49] presents SA results but the method used is not specified. The advantages and limitations of methods a discussed in the following section (Discussion).

Psychophysiological data may also be used to assess SA. For example, eye-gaze can be used to measure level 1 of the SA (perception level). six articles [36], [38], [52], [59], [68], [69] included eye-tracking in their evaluation methods as process indices method.

Some ***driver's performance indicators*** may also be used to estimate situation awareness. In particular, TOR performance indicators, such as reaction time (RT) and time to collision (TTC) may constitute good metrics for assessing situation awareness. Thus, [36], [59], [61] evaluate driver's takeover performances, [30], [40], [44], [52], [53], [56], [59], [66], [69] assess driver's reaction time, [44], [67] evaluate driver's behavior and [50], [52], [54], [60], [65]–[69] assess other performances such as number of collisions, time to collision, lane deviation or driving data. The task accuracy is also often assessed in the experiment presented [30], [40], [53], [56], [64].

Situation awareness and ***workload*** are closely related. According to Endsley [71], high SA and low workload is the ideal design to target and it is important to assess both SA and workload during test and evaluation. Thus, [30], [44], [45], [47], [53], [55], [62], [65], [66], [69] evaluate the workload using the NASA-TLX questionnaire, [55] uses the DALI and [58] RMSE (Rating Mental Scale Effort). [68] assesses the visual workload.

Finally, part of the evaluation also focuses on the user experience of participants. So, in order to assess ***acceptability***, [60] used the questionnaire proposed by Venkatesh [72] and [66] the Arndt's one [73]. [36], [50], [65], [68] used custom questions and Likert scale or Linear Analog Visual Scale [46]. [30], [54], [61], [67] measured ***both acceptability and usefulness*** using the van der Laan's usefulness and acceptance system [74]. In order to evaluate ***usability***, [30] performed a System Usability Scale (SUS) [75] questionnaire, whereas [37] clustered positive and negative aspect from interviews analysis and [57] used a 0-10 scale. [47] assessed the ***annoyance*** of the system. Concerning the usefulness, [38], [68] used scales. [45] assessed the user experience with the User Experience Questionnaire (UEQ) [76]. [37], [38], [43], [57], [64] performed general interviews and [30], [36], [38], [50], [60], [69] assessed participant's ***trust*** in the system with different ranking and Likert scales. [60] used the trust in specific technology scale [77].

C. Overview HVI to assess driver's situation awareness (RQ3)

As mentioned in the introduction, there are different ways to assess the situation awareness. However, these methods often allow to obtain subjective data (with the SART for example). Or, they are sometimes complicated to implement in the driving domain because it requires to freeze the simulation (SAGAT), which can have an impact on the immersion of the participants. Moreover, these methods were mainly developed initially in the aviation domain. Thus, this section highlights one research that aims to develop methods to measure the driver's awareness.

Sirkin et al. [29] proposed an interface called DAZE for assessing situation awareness in real-time. Their technique is based on-road event question. When an event happens (e.g. an accident), the application alerts the driver and ask for a confirmation if the event is still present. The application consists of a screen positioned on the center stack on which a map of the vehicle's environment (roads, places) and an egocentric representation of the vehicle are displayed. The alerts are also displayed on this screen and are completed by two buttons ("yes" and "no") to allow the driver report if she has seen the event described by the message or not. The different common types of events that a driver may encounter are locations of police officers, road construction, school zones, heavy traffic, accidents, and road hazards (such as an object in the road). The authors conducted tests to validate their technique to assess the driver's situation awareness. For this, they conducted an experiment in a simulator but also on the road (Wizard of Oz). They demonstrated that this technique collects data useful for measuring situational awareness and separate the measurement of SA from driving performance. The purpose of the road tests is to propose alternative interface concepts. The current results focus more on navigation and messages.

D. Meta-analysis overview

As a reminder, this part was performed on 29 articles and presents a qualitative synthesis because of the variability of study designs, number of participants (as mention above), interaction modalities, and outcome measures.

When participants are engaged in a visual-only NDRT, the presence of ambient lights on the dashboard does not yield significant results [38]. Nor did audio-visual modalities combining sound with icons on the dashboard [64], center stack [67], or icons and text on the windshield [68]. Similarly, text and icons on the center stack when performing a visual and biomechanical NDRT does not show significant results [44].

Regarding the meta-analysis of results on ***SA***, 17 articles reported significant results regarding the use of their interface. With respect to how SA has been measured in these studies, [45], [46], [66], [67] assessed situation awareness with a SAGAT, [42], [53], [58], [60], [67] used a SART questionnaire, [48], [59] analyzed gaze behavior, [30], [50] evaluated secondary task performances, whereas [36] analyzed both gaze behavior and NDRT performances. [37] studied the accuracy of guessed intentions. [57] and [55] assessed SA with subjective questions. [43] used DAZE technique. Two articles mentioned not having obtained significant results. [54] used a SAGAT whereas [64] assessed SA using task accuracy performance in identifying events. However, they still showed positive trends. [47] did not asses SA directly but they concluded that speech displays should be considered to support SA because they presented significant results for maintaining memory of event.

12 articles ([30], [40], [41], [50], [53], [54], [59]–[62], [65], [69]) showed a positive impact of their interaction on ***TOR*** (better behavior) and reduced ***reaction time***, while four articles [36], [44], [56], [66] present non-significant results.

Regarding the ***confidence*** in the system, six articles ([30], [36], [45], [50], [57], [60]) report significant results while three articles ([54], [64], [69]) report non-significant results. Finally, 15 articles ([30], [36], [37], [45]–[47], [50], [54], [57], [59]–[62], [65], [68]) report significant results on the ***user experience***. Participants showed good user experience with these interfaces. Globally, this kind of interfaces does not disturb the driver, with a good acceptance and perceived usefulness. However, three articles ([43], [66], [69]) did not have significant results on the use of their interface.

Overall, it appears that auditory-only interactions are not effective in maintaining driver SA. However, visual, audio-visual interactions and interactions combining haptics and visual seem promising to support the drivers' SA, while maintaining at the same time their confidence in the system and a good user experience.

V. Discussion

The objective of this section is to summarize the results presented above and discuss them in order to answer our research questions. Then, we discuss the limitations of the obtained findings.

A. Summary and discussion

1) RQ1: The first objective of this review is to identify how HVI can be designed to support supervision and situational awareness in conditionally automated driving **(RQ1)**.

Overall, the most transmitted information concerns the vehicle itself (its status but also its intentions), the obstacles around the vehicle and external human factor (traffic, other users and temporary obstacles or hazards) Table II. As this information is mainly transmitted through visual interactions (text and icons on the windshield/HUD [30], [45], [46]) and audio-visual interactions (icon or text combining with a chime [52], [61], [62], [65]), Figure 3. The use of lights shows also significant results to maintain SA, they are mostly placed under the windshield ([30], [36]), on the center stack ([37]), the steering wheel ([41]) or the periphery of view ([37], [43]). Vibrations are used to communicate the vehicle intention on the driver's wrists ([57], [58]) or in the seat to inform about the traffic ([59]). Multimodal modalities combining vibration in the seat, light on the periphery and icons on dashboard and center stack also present significant results conveying vehicle's uncertainty [69].

However, these interactions tend to be more and more peripheral and support this shift in the driver's attention to help him/her supervise the surrounding environment in a peripheral and non-intrusive way (Figure 4). Indeed, the majority of the interactions cited meet the criteria defined by Matthews [78] namely abstraction, notification levels and transition between changes. To meet the characteristics of abstraction, many propose the use of icons and symbols, sounds or even earcons or vibrations (Tables I and II) in order to convey detailed information such as hazards, obstacles around the vehicle, heavy traffic, etc... The levels of notification are mostly implemented by the use or not of modalities (appearance of an icon, a sound or a vibration). Kunze et al. [69] propose as levels of notification change in size and color hue for the visual displays and pulse frequency for the haptic seat. For most audio-visual interactions, sound is often used to notify this transition.

Overall, the results of the meta-analysis show that the use of ambient lights is effective in communicating vehicle intentions ([37], [42], [43]). The peripheral use of vibration to transmit information about the vehicle's intentions or traffic directly to the driver's wrists ([57], [58]) or in the seat [59] also shows significant results. Audio-visual interactions combining sound and icons ([66]) or sound and icon+text ([60], [67]) also show significant results in maintaining driver's situation awareness.

For the moment, there are few multimodal interactions using different parts of the vehicle but these researches tend towards positive results. It could be possible to develop interfaces that adapt in terms of modality and/or location according to the driver state and emotion and the driving and interaction context (environment and NDRT) in order to maintain in an efficient way the driver's situation awareness. For example, De Salis et al. [79] propose the design of an AI-companion to support driver in highly automated driving. The objective of this companion is to design adaptive HMIs considering the state of the user and the current external situation (state and behavior of the vehicle) in order to maintain the user's awareness and to propose an adapted TOR. Moreover, other modalities not found in our review but currently studied in the context of manual driving could also be transposed in the context of autonomous driving. For example, Dmitrenko et al. [80] use multiple scents in order to convey driving-relevant information such as slow down, distance between vehicle too short or lane departure messages. Bordegoni et al. also confirm that olfactory stimuli are effective on driver's attention [81], more than auditory stimuli.

Temperature could also be used as modality to influence the driver's SA. Indeed, Schmidt et al. [82] demonstrate that thermal stimuli can mitigate driver's passive fatigue during monotonous driving. Thus, it would be possible to vary the temperature in the cabin if the vehicle detects a state of fatigue of the driver during the autonomous driving phase. In another context that is not related to driving, Teweel et al. [83] explore the use of temperature changes as navigation cues.

Another criterion that would be interesting to take into account in the development of such interfaces is the state of the driver. Indeed, Merat et al. [84] showed that, during autonomous driving, it is important to consider the driver's state and more specifically the cognitive workload. Thus, it would be possible to adapt the type of modality(ies) used as well as the interface according to the level of fatigue or stress of the driver [79]. Knowing where the attention is focused, would be also useful. For example, if the driver is looking at the windshield, it would be possible to transmit information using the HUD, but if his attention is focused on reading the newspaper, it would be possible to combine this interaction using vibrations in the seat or a sound. The concept YUI [70] propose appropriate multisensory input and an embodiment of vehicle. The information should be provided in the right time according to the situation and the driver state and the system should also be able to anticipate driver's need.

2) RQ2: The second objective of this analysis is to synthesize how the different interfaces are evaluated in the different studies **(RQ2)**.

Overall, most of the experiments were carried out on fixed-base simulators (25 out of 30 searches with experience). This shows that few concepts have been actually tested in real driving conditions. In a TOR context, Sadeghian et al. [85] have shown that the real movements provided by a simulator influence the participants' control takeover. Indeed, their results show that participants are sensitive to motion-related information and that it is important to take this data into account to support the driver in his decision making. Therefore, evidence found in fixed-base simulator experiment might not be always directly transferred to real-world scenarios even if the use of fixed-base simulators is valid for experimenting driving performances [86], [87]. In the future, more research should be conducted on real roads to validate the findings in this area.

Moreover, age and gender differences are not taken into account even though it has been shown that gender can have an impact on hue sensations [88] and spatio-temporal resolution [89]. This is a notion that could be interesting to take into account when designing and evaluating interfaces with such characteristics. When it comes to driving, age can have a big impact. Indeed, in addition to diminishing certain capacities such as hearing or vision, age also has an impact on the willingness of older people to continue driving [90], [91]. The design and development of interfaces that take into account the age of these people and their abilities could allow them to stay on the road safely longer.

22 studies report the performance in a non-driving task during autonomous driving phases. NDRTs are used to divert the driver from the task of monitoring the environment and therefore are important to assess the effectiveness of the interface being evaluated. The majority of NDRTs are visual. Indeed, the driver does not see what is going on in the environment of the car while performing visual NDRTs. Thus, HVIs can be beneficial in keeping the driver informed about the surroundings and about the vehicle intentions. It is in line with finding of Large et al. [60] suggesting that most drivers would engage in visual NDRTs. Indeed, in their study, participants experienced three phases of autonomous driving over the 5-day experiment. During these phases, they could perform any activity of their choice. The results show that they spent the majority of their time on their phone. Some were reading a book/newspaper or watching the road. The time spent looking at the road diminished with each passing day.

From the results of our analysis, SAGAT and SART are the two most used methods for evaluating drivers' SA. However, these two evaluation methods don't assess exactly the same aspect of SA. Indeed, in a comparative analysis of SART and SAGAT, Endsley et al. [92] concluded that SART results are more correlated with their level of confidence in situation awareness whereas SAGAT provide an objective measure of the three levels of SA based on specific context queries. Endsley [93] also proposed a systematic review of SA measurement technique and compared the SAGAT with a method called SPAM (Situation Present Assessment Technique) and their variants. SAGAT and SPAM are equally predictive of performance, but SAGAT is more sensitive and more intrusive. Other performances such as TTC, TOR and driver's behavior are also mentioned to assess SA and effectiveness of HVI. Moreover, in order to evaluate the benefits of an HVI in terms of situation awareness, it is important to create a well-defined scenario involving non-driving task that can be cognitive enough to simulate the driver's engagement in this task.

The confidence of the drivers in the different systems studied is also measured and contributes to the concept of situation awareness. Indeed, it would be possible to think that overconfidence towards autonomous systems implies a bad situation awareness. Similarly, a lack of confidence in the vehicle could lead to increased situational awareness, as the driver would be intensely monitoring his or her environment, but would also cause additional fatigue or stress. Nevertheless, Tesla accident example [94] shows that over-trust is dangerous in this field that is why trust is an important factor to take into account. Additionally, Petersen et al. [95] assert that SA "awareness both promoted and moderated the impact of trust in the automated vehicle, leading to better secondary task performance" which shows that SA and trust are strongly linked. It is in this sense that Holthausen et al. [96] propose a new evaluation scale called "Situational Trust Scale for Automated Driving" (STS-AD) because trust is strongly situation dependent.

3) RQ3: The third objective of this analysis is to investigate how the interfaces developed to measure driver's SA are designed **(RQ3)**.
The search for an interface to measure driver SA in autonomous driving could only bring forward the study proposing the DAZE interface [29]. At present, the main methods for measuring driver SA are the use of questionnaires such as the SART or SAGAT. Unfortunately, SAGAT requires freezing the simulation which can cut off the driver's immersion and SART is a post-trial questionnaire that may not assess SA in the right moment but more in a general way. Eye-tracking techniques can be used to measure at least the first level of SA (perception) as proposed by [36], [59], [69]. In the field of aviation, Van de Merwe et al. [97] showed that eye movement could be an indicator to measure SA. The use of fixation rates and dwell times can be used as indicators of information acquisition (Level 1 - Perception). They use the randomness if visual scanning behavior as an indicator of new information acquisition activities (Level 3 - Projection). Thus, this finding and the promising results of DAZE technique [29] of assessing situation awareness through recall events show that it would be interesting to develop new interfaces to measure SA subtly for higher levels of automation.

Another paper that did not meet the eligibility criteria and thus was removed from this analysis also proposed an interface to measure SA in teleoperated driving [98]. They developed a supervisory user interface based on the SAGAT methodology. Even if there is no statistical analysis this exploratory study and the first results show a promising approach of assessing SA through human-robot interface.

B. Summary of findings and directions for future development

To summarize, ***Evidence (RQ1):***

- The most conveyed information concerns the vehicle's status and intentions, obstacles and external human factor.
- Interactions are mostly visual and audio-visual. Few multimodal interaction had been evaluated.
- We observe significant results with the use of several interfaces: ambient lights increase SA about vehicle intentions, the peripheral use of vibration directly to the driver's wrists or in the seat maintain SA about the vehicle's intentions or traffic such as audio-visual interactions combining sound and icons or sound and icon+text.

Evidence (RQ2):

- Most of the experiment were carried out on fixed-base simulator.
- The majority of NDRT performed are visual.
- SAGAT and SART are the two most used methods.

Evidence (RQ3):

- Only one study proposes an interface to assess driver's SA.

Directions for future development:

- Other modalities such as temperature may be explored [82], [83].
- Multisensory stimuli and embodied vehicle interfaces may be explored [70].
- Adaptive HVIs according to the situation and driver's state may be considered [79].
- More research should be conducted on real roads or immersive motion-based simulators.
- Confidence should be considered in order to alleviate the problems of under-reliance and over-reliance [96].
- More in-vehicle interfaces should be explored in the future [29], [98].
- Interface designs could be thought of to allow the elderly to stay longer on the road in complete safety [99].

C. Results limitations

This study is an overview of the existing concepts and of the technologies developed to maintain SA. The results point out some research areas where there are a lot of studies and also highlights domains where there is less research but promising results can be expected. However, since the interfaces (interaction modalities and location) are very different throughout all the corpus and they do not convey the same type of information (see Table II), it is not always possible to directly compare all the findings. There is a large variety of research with different characteristics such as the number of participants, the duration and extent of the experiment (less than one hour or several tests during the week). Moreover, as the analysis on the modalities shows, the distribution of these search areas is not at all balanced, there are for example much more research focusing on the visual modality. It is therefore not possible to conclude, for example, that "visual is the most effective modality for maintaining driver SA". Nevertheless, our review could be helpful to point out common practice in the field and compare future results with previous studies. Considering the number of parameters that can affect the results of a study on situation awareness, it is important to build on previous results in order to be able to derive findings that could be considered as generally valid. Moreover, the validity of the results obtained so far can be affected by the fact most of the studies were conducted in fixed-base simulators rather than in real-driving scenarios.

From the methodological perspective, we tried to frame our results according to existing taxonomies or frameworks. We hope that such approach can facilitate further comparisons with future studies. However, in some cases, a rigorous taxonomy was difficult to obtain, because of the nuances that can be found in each aspect analyzed in our paper. For example, the classification of the type of interactions according to the interaction-attention continuum (peripheral, focused, implicit), required the creation of intermediate categories such as ”peripheral-implicit” or ”peripheral-focused”. Framing the interactions among these categories may lead to subjective interpretations since there is no specific information about how long the driver must stay on a visual cue to consider him/her ”focused”. Such information is also seldom reported, as it can be measured only with eye tracking. Moreover, even if there are studies considering several components in the design of peripheral interactions such as Matthews et al. [78], [100], Pousman et al. [101], we did not analyze the following articles these components. This point could be addressed in an extension of this work and thus evaluate the proposed interfaces according to the instructions given by the previous authors. As for example based on the four dimensions from Pousman et al. (information capacity, notification levels, representational fidelity and aesthetic emphasis) or Matthews et al's characteristics (Abstraction, Notifications levels and Transitions between changes) and criteria (appeal, learnability, awareness, effects of breakdowns distraction).

D. Recent updates

Since this study only covers articles from 2012 to 2020 with a decrease in the number of articles on the topic after 2017 (see figure 2), we performed a quick analysis on the years 2020 to 2022. For this, we reused the query mentioned in the appendix in the ACM library database. We obtained 10 eligible articles on this research (four from 2020, five from 2021 and one from 2022). In general, the results presented above do not change and are even confirmed by this new analysis. Indeed, nine out of ten articles discuss about the use of visual modality. Six researches propose display information on the windshield (HUD) mostly in augmented reality [102]–[107] whereas [108] used the center stack. [109] displayed light on dashboard (above) and [104] on the pillars. [104] compare also the icons, text visualization on the windshield and light with chime and haptic seat. [110] conveyed context related information through icons on personal device (tablet). One article proposed the use of thermal feedback (hot and cold) on driver's face in order to convey information about other cars and temporary obstacles [111]. The newest articles show that the visual modality is still the most investigated, with a particular interest for future augmented reality interactions. Current augmented reality studies were conducted until now with interfaces integrated in the virtual simulation or in a prerecorded video. Further research should be still conducted in order to bring this interaction concepts to real vehicles.

VI. Conclusion

A systematic review was conducted to analyze previous studies carried out in the field of Human-Vehicle Interaction for supporting driver's situation awareness during the autonomous driving phase. Our goal was to study how they are designed, in particular in terms of the type of attention required [21], and how they are evaluated. This systematic review has shown that the use of peripheral interaction using different parts of the vehicle is effective in keeping the driver in the control loop, but the modalities implemented and their location are very important to consider. To show this, we analyzed the modalities used in the different concepts presented but also their location in the vehicle, their type of interaction with the driver and the type of information transmitted. The majority of the presented interfaces act mainly on the peripheral attention of the driver or switch on the continuum between peripheral and focused attention. Moreover, the analysis shows that the majority of the presented interactions are visual interactions and use the windshield and/or the center stack as interface. The meta-analysis highlighted 17 articles with interfaces that significantly maintain driver SA. These studies presented a lot of variability in terms of the interfaces that were tested and on the modalities of assessment, therefore it is not possible at present to derive specific recommendations on what is actually effective in maintaining SA.

Through this systematic review, we have also analyzed the evaluation methods of such interfaces. The majority of the experiments are performed on fixed-base simulators. The main methods for measuring SA are mainly subjective (SART and SAGAT) but other objective measures are also used to evaluate SA such as take over request behavior, reaction time and gaze. It is also important to consider the performance of a non-driving task in the evaluation of IMH. Indeed, Vogelpohl et al. [4] has shown that the absence of a secondary task during the autonomous driving phases makes the trip much more monotonous and increases driver's fatigue. They concluded that ”driver fatigue monitoring or controllable distraction through non-driving tasks could be necessary to ensure alertness and availability during highly automated driving”.

Last but not least, only one work seems to propose another way to assess situation awareness using the interaction implemented in the vehicle [29]. The promising results of this study show that it may be possible to combine the means of maintaining driver SA and the way of measuring it.

To conclude, the purpose of this article is to propose an overview of the work done in the design and development of HVI to maintain driver SA for vehicles of level 3 and above. This systematic highlighted different criterion of classification that may help researchers to have an overlook of the work already done or in progress in order to improve existing concepts or to propose new interfaces such as adaptive interfaces.

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Databases and queries

Table IV illustrates databases and query used.

Source	Query
ACM	(+(SA ”situation* awareness” loop alert* ”driver attention” ”peripheral attention” ”peripheral interaction”)+(car* vehicle* driver automobile) +(”automated driving” ”autonomous driving” ”highly automated driving” ADAS ”semi autonomous driving”) +(measure* hmi ”human machine” ”user centered” ”human computer” ”human factors”))
IEEE	((SA OR ”situation* awareness” OR loop OR alert* OR ”driver attention” OR peripheral*) AND (car OR vehicle OR automobile) AND (”*automated driving” OR ”autonomous driving”) AND (measur* OR hmi OR ”human machine” OR ”human computer” OR ”user centered”))
Elsevier	({situation awareness} OR {driver attention} OR {peripheral attention} OR {peripheral interaction}) AND ({automated driving} OR {autonomous driving}) AND (measure OR hmi)) dans tak
Plos One	(everything:sa OR everything:”situation* awareness” OR everything: loop OR everything: alert* OR everything: ”driver attention” OR everything: ”peripheral interaction”OR everything:”peripheral attention”) AND (everything:Car OR everything:Driving OR everything:vehicle OR everything:automobile) AND (everything:”*automated driving” OR everything:”*autonomous driving”) AND (everything:hmi OR everything:”human machine” OR everything:”human computer” OR everything:”user centered” OR everything:”measur*”
Scopus	TITLE-ABS-KEY ((”SA” OR ”situation* awareness” OR loop OR alert* OR ”driver attention” OR ”peripheral attention” OR ”peripheral interaction”) AND (car* OR vehicle* OR driver OR automobile) AND (”automated driving” OR ”autonomous driving” OR ”highly automated driving” OR adas OR ”semi autonomous driving”) AND (measure* OR hmi OR ”human machine” OR ”user centered” OR ”human computer”))
Web of Sciences	((TS=(”SA” OR ”situation* awareness” OR loop OR alert* OR ”driver attention” OR ”peripheral attention” OR ”peripheral interaction”) AND TS=(car* OR vehicle* OR driver OR automobile) AND TS=(”automated driving” OR ”autonomous driving” OR ”highly automated driving” OR ADAS OR ”semi autonomous driving”)AND TS=(measur* OR hmi OR ”human machine” OR ”user centered” OR ”human computer” OR ”human factors”))) AND LANGUAGE: (English)
PubMed	((”SA” OR ”situation* awareness” OR loop OR alert* OR ”driver attention” OR ”peripheral attention” OR ”peripheral interaction”))) AND ((car* OR vehicle* OR driver OR automobile))) AND ((”automated driving” OR ”autonomous driving” OR ”highly automated driving” OR ADAS OR ”semi autonomous driving”))) AND ((measur* OR hmi OR ”human machine” OR ”user centered” OR ”human computer” OR ”human factors”))

TABLE IV
DATABASES AND QUERIES

GLOSSARY

Focused interaction Requires focused attention. The user cannot perform another important task in parallel (for example, driving and texting).. 2

HVI Human-Vehicle Interaction. Human-Machine Interaction concept applied in the automotive field. 1

Implicit interaction Does not require explicit commands from a user - systems that act autonomously based on sensor input (it is an autonomous system that is not designed to deliver explicit information to the user).. 2

Level 2 SAE System provides continuous assistance with both acceleration/braking AND steering, while driver remains fully engaged and attentive. You, as the driver, are responsible for driving the vehicle. When engaged, the system can perform steering AND acceleration/braking. 1

Level 3 SAE System actively performs driving tasks while driver remains available to take over. When engaged, the system handles all aspects of the driving task while you, as the driver, are available to take over driving if requested. If the system can no longer operate and prompts the driver, the driver must be available to resume all aspects of the driving task.. 1

Level 5 SAE	System is fully responsible for driving tasks while occupants act only as passengers and do not need to be engaged. When engaged, the system handles all driving tasks while you, now the passenger, are not needed to maneuver the vehicle. The system can operate the vehicle universally – under all conditions and on all roadways. A human driver is not needed to operate the vehicle.. 1
NDRT	Non-driving related task. Any task not directly related to the driving task that the driver can perform during the autonomous driving phases (e.g. reading, writing an email). It is not a secondary task.. 1
Peripheral interaction	Perceived in the periphery attention - outside of the focus of attention: interactions apply to the peripheral field of view of the user or it is a brief action performed in parallel to other activities or to include both surrounding perception and surrounding interaction. 2
Situation Awareness	The perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status. 1
TOR	Take over request. A TOR occurs when the automated system exceeds operational limits and has to revert control back to the driver.. 1

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A Biography Section

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Leonardo Angelini is currently Professor at the School of Management of Fribourg and works as a researcher in the HumanTech Institute. He holds a PhD in Computer Science, conducted in a cooperation between the University of Applied Sciences of Western Switzerland (Fribourg), and the University of Fribourg. His research domains are in the area of Human-Computer Interaction, with particular focus in gesture interaction, tangible interaction, multimodal interaction, affective computing, with several year of experience in vehicular applications and participative design with seniors.

Quentin Meteier is a PhD student at University of Fribourg and the HES-SO University of Applied Sciences and Arts Western Switzerland. He is working on conditionally automated driving and focuses his research on evaluating the physiological state of the driver using machine learning techniques.

Omar Abou Khaled received the B.Sc. degree in computer engineering, in 1991, and the master's and Ph.D. degrees in computer science from the HEUDIASYC Laboratory, Perception and Automatic Control Group, Université de Technologie de Compiègne. He is a Professor with the University of Applied Sciences of Western Switzerland. Since 1996, he has been working as a Research Assistant with the MEDIA Group of the Theoretical Computer Science Laboratory of EPFL in the field of educational technologies and web-based training research field on MEDIT and CLASSROOM 2000 projects.

Elena Mugellini received the master's degree in telecommunication engineering and the Ph.D. degree in Telematics and Information Society from the University of Florence, in 2002 and 2006, respectively. She is a Professor with the Information and Communication Department, University of Applied Sciences of Western Switzerland (Fribourg). She is the Leader of the HumanTech Institute. She is also a member of the Telematics Technology Laboratory, University of Florence. Her current research interests include ambient intelligent, multimodal interaction, natural interface, intelligent data analysis, information, and knowledge management.