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End-users perspective matters in ADAS: designing a blind-spot alert system from a user-centered approach

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Abstract The number of traffic accidents involving motorcycles has been increasing in Brazil recently. Many accidents are caused by drivers who do not see motorcycles approaching in the vehicle blind spots. Advanced Driver Assistance Systems (ADAS) installed in vehicles can be used to mitigate this problem. However, the development of ADASs often focuses on security issues and does not consider the user experience with the ADASs interface. In this paper, we present the design of an alerting system that warns drivers about collision risks when motorcycles are identified in vehicle blind spots. Our proposal alerts drivers by using visual and haptic interaction modes. Following a user-centered design approach, our initial action involved identifying traits of the target users in order to create personas that embody their characteristics. The vehicle blind spot alert system was conceived in a co-design session using the personas elaborated previously. In the session, nine end-users produced three low-fidelity (lo-fi) prototypes which were then compiled generating a single lo-fi prototype. After, a technological viability discussion was carried out. As a result, a high-fidelity (hi-fi) prototype containing haptic and visual alerting features was implemented and installed in a vehicle for testing. The alert system was evaluated by 20 end-users concerning their experience with the different warning modes. The results showed that for both the visual and haptic modes, users could recognize and understand the alerts without employing a great effort in the information interpretation. This result reinforces the idea that ADASs should provide simple interpretative interfaces because drivers' interaction with these systems should be a secondary activity since their concentration must be on driving.

Keywords: Notification System, User Experience, Advanced Driver Assistance System, ADAS, Personas, Co-design workshop, Situation Awareness

1 Introduction

Traffic accidents involving vulnerable user vehicles, such as motorcycles and bicycles, are mainly caused by drivers' lack of attention to vehicle blind spots [de Paula Brito *et al.*, 2014; Shen and Yan, 2018]. This occurrence of accidents can be attributed to factors, such as the small size of motorcycles, which consequently introduces a greater challenge for drivers to detect them [Seerig *et al.*, 2016]. In addition, the aggressive riding patterns usually present in motorcycle drivers can contribute to the increase in accidents [da Silva, 2020]. Therefore, the purpose of solutions that allow drivers to recognize motorcycles positioned in the vehicle's blind spot is essential for safe driving.

The adoption of the *Advanced Driver Assistance System* (ADAS) can assist drivers in mitigating the problem described above. ADAS is a system that integrates software and sensors to be able to alert drivers in different critical situations (e.g., rear camera). The work of Cicchino [2018] revealed a significant reduction in the rate of accidents during maneuvers (e.g., changing lanes) in vehicles that contained blind spot monitoring systems. ADAS usually addresses fundamental aspects of driving safety and efficiency. However, aspects related to driver comfort or enhancements in their ADAS experience are often neglected Paiva *et al.* [2021].

There have been some investigations into how drivers engage with ADAS and the impact of this interaction in terms of attention and information interpretation efforts [Frison *et al.*, 2019a; Sun *et al.*, 2021]. Nonetheless, few studies have focused on designing ADAS by putting the end-users in the centered of the process [Sun *et al.*, 2021; Yun *et al.*, 2019; Li *et al.*, 2020]. Designing ADAS with the participation of drivers not only enhances user interaction and communication with the system but also impacts crucial traffic safety decisions, as it can reduce the cognitive effort required for drivers' interpretation Sun *et al.* [2021]; Abendroth and Bruder [2016].

The insufficient emphasis on user experience can be attributed to the necessity of addressing other complex elements related to the driving activity Abendroth and Bruder [2016]. Various levels of vehicle automation require consideration of different aspects of the user experience [Frison *et al.*, 2019b]. At advanced levels of automation, the primary focus of the user experience is on providing comfort and enjoyment during non-driving activities [Sun *et al.*, 2021]. Conversely, at basic levels of automation, the user experience should prioritize keeping the driver's attention on driving. Moreover, drivers tend to ignore the alert systems and their safety features when these systems are not designed taking into account good user experienceOrlovska *et al*. [2020]. Despite this, blind spot notification systems for motorcycles are still under-explored currently. Most existing ADAS for alerting about blind spot hazards primarily involve showing a light on the vehicle dashboard.

Taking into account the motivation mentioned above, this paper intends to introduce an alert system for drivers when motorcycles are detected in the vehicle's blind spot. Our research method employed a user-centered design approach comprising four stages: an investigation of end-user characteristics with 11 drivers, a co-design session involving 9 end-users to design the alert system, the development of a functional prototype, and an assessment of the proposal with 20 end-users. The evaluation results indicated that the proposed system required minimal interpretation effort and attention in relation to the notification formats implemented. This research makes two key contributions. The first refers to the method used to design the proposal. The co-design approach is uncommon in the automotive industry, although it has been shown to be an effective tool for grasping the actual needs of the users involved. In addition, there are few studies that address user experience in the automotive sector. The second contribution focuses on the notification formats created to address the challenge of detecting motorcycles in a blind spot. Based on the research conducted, this proposal differs from the existing literature and practices in such systems.

The remainder of the paper is organized as follows. Section 2 covers the concepts of user experience and ADAS, as well as related work. In Section 3.1, the research method used and the research questions that guide the studies are detailed. Section 4 provides an overview of the study centered on understanding the characteristics of the drivers. Sections 5, 6, and 7 describe the procedures and findings of the co-design workshop, the development of the functional alert system, and the evaluation of the proposal, respectively. Finally, Section 8 addresses the research questions, discusses the findings, and points out the limitations of our study, while Section 9 offers the concluding remarks and potential directions for future work.

2 Background and Related Work

This section presents the fundamentals and related work about UX, UCD and co-design, and their relation with the development of ADAS.

2.1 Background

Different (*User eXperience* - henceforth UX) can be found in the literature. The ISO standard [ISO Central Secretary, 2019] defines user experience as the user's relationship with the use of the product before and during its acquisition. Hassenzahl and Tractinsky [2006] states that UX is influenced by a user's internal state (expectations, needs, motivation), the product's characteristics (purpose, usability, functionality), and the external context (organizational, social, and environmental factors). The definition of Hassenzahl and Tractinsky [2006] places on the first plan the relevance of exploring the tripod composed of users, the system, and the context of its use. Considering the tripod, User-Centered Design (*User-Centered Design* - UCD) approach can be adopted to support the construction of more user-centered solutions. It considers the needs of users and their expectations during all stages of product development to gradually find a solution [Still and Crane, 2017].

Empathy between users and designers is crucial to understanding user needs[Knight, 2018]. Personas are powerful tools for building this connection, improving product quality and usability [Cooper, 1999; Cooper and Reimann, 2003]. A persona is a detailed representation of a specific user group, providing information on their demographics, behaviors, preferences, and needs [Knight, 2018]. Personas are elaborated from data gathering in qualitative or quantitative studies; they enable more effective decision making and tailored strategies without the need for direct interaction with individuals. Personas can effectively support designers and developers in UCD activities by providing detailed characteristics of user groups.

Among the various methods and techniques for developing UCD, *cooperative design*, also referred to as co-design or participatory design, stands out. Co-design involves creating solutions to real-world problems by actively engaging users and other stakeholders interested in solving the problem Braa [1996]; Sharp *et al*. [2019]. This method encourages discussions from multiple perspectives and facilitates greater user participation in generating new ideas that align with user needs. The co-design process can be implemented through *workshops* (workshops) with the participation of end users, domain specialists, and HCI professionals Sharp *et al*. [2019].

In the automotive industry, the various devices installed in vehicles can influence UX. Currently, vehicles are outfitted with ADAS which offer tools to aid drivers in managing driving tasks (e.g., rear cameras, sound alerts) [Braun *et al*., 2019]. The primary goal of ADAS is to enhance traffic safety and deliver comfort, leading to a better driving experience. However, it has been noted that users often disable many ADAS features, potentially because these systems may be designed focusing solely on safety, neglecting other UX factors [Hasenjager *et al*., 2020]. Interaction with ADAS involves several cognitive processes, including the interpretation of ADAS messages. These messages should be easily and quickly understood; otherwise, the user's trust in the product can be diminished [Kraft *et al*., 2020], alongside overall traffic safety.

Additionally, *Society of Automotive Engineers International* (SAE International) in collaboration with *International Organization for Standardization* (ISO) developed a classification system detailing levels of vehicle automation featuring ADAS. According to this classification, at the lowest level (level 0), the driver maintains full control and responsibility for driving the vehicle. In contrast, at the highest level (level 5), the vehicle autonomously manages direction and makes decisions in all traffic situations [SAE International, 2018].

2.2 Related Work

At the lowest levels of automation, the task of managing vehicles still regards the human individual as the main agent responsible for this task [SAE International, 2018]. The main difficulty in carrying out the UCD approach in the automotive domain is caused by the fact that warnings are provided to users while they are driving, which is the main activity at that time [Abendroth and Bruder, 2016]. Consequently, notifications can inform drivers at the same time that ensure that they remain alert [Frison *et al*., 2019b].

Lindgren *et al*. [2007] propose the use of *personas* to guide the design process of an ADAS. The authors construct four *personas* (i.e., Claes, Kristina, Mats and Camilla) using a demographic database from a vehicle manufacturer, combining the results with a series of semi-structured interviews. ”Claes” is a 64-year-old man and experienced driver, who gets easily annoyed in traffic and remains constantly aware of the situational context. Although he likes technology he faces difficulties in interacting with it. ”Kristina” is a 62-year-old woman who takes a calm, defensive stance. She has no interest in automotive technology and often operates electronic devices while driving. ”Mats” is a 44-year-old technology enthusiast who often does secondary activities while driving, such as talking on the phone or smoking. Finally, ”Camilla”, a 38-year-old woman, lacks confidence in her driving skills, leading her to adopt a defensive and vigilant approach. However, she feels uncertain when faced with challenging traffic conditions. The four personas were validated in a workshop.

Brinkley [2021] uses the *personas* technique to explore the accessibility of two ADAS interface designs. The authors describe in short detail three personas who have some kind of visual impairment. These personas were then used in a series of participatory design sessions with co-designers who also had some kind of disability. This approach served as a guide for building an interface that satisfied the users’ requirements. The results mainly pointed to the need for clear and concise notifications about the surrounding environment.

Based on the premise of keeping the driver in an awareness situation, Sun *et al*. [2021] carried out three studies involving requirements analysis, co-design, and user validation for the design of a new interior of *Highly Automated Vehicles* (henceforth HAV). In the evaluation, the authors applied the *Situational Awareness Rating Technique* (henceforth SART) to measure the awareness of users about the new design. The findings suggest that users exhibit enhanced situational awareness when aided by a visual notification tool [Sun *et al*., 2021].

Conversely, at the most advanced levels of automation, the roles are reversed, and thus, the design of the user experience prioritizes comfort and enjoyment [Frison *et al*., 2019b]. In a study by Frison *et al*. [2019a], the impact of user-directed context on their experience was analyzed using a simulator, supplemented with participant interviews. The findings indicated that factors like traffic density and road type significantly influence UX. The researchers identified a series of factors categorized into layers—technical restrictions, user interface, UX quality evaluation, psychological needs—to illustrate how UX may be influenced, particularly at higher vehicle automation levels. In subsequent research, Frison *et al*. [2019b] assessed the set of factors and introduced an additional layer concerning condition. Statistical tests indicated that among the aspects of affection, security was notably positively perceived. All identified layers form a *framework* termed *Driving Automation UX framework* (DAUX) [Frison and Riener, 2022].

Several studies have examined the impact of drivers’ age on user experience (UX) [Braun *et al*., 2019; Günthner and Proff, 2021; Li *et al*., 2019]. Quantitative research assessing the use of typical Advanced Driver Assistance Systems (ADAS) available on the market, such as cruise control, indicated high acceptance rates among older adults [Braun *et al*., 2019]; however, there was less acceptance observed among younger drivers [Günthner and Proff, 2021]. Semi-structured interviews with elderly individuals (60+ years old) Li *et al*. [2019] revealed that customizing the notifications issued to drivers based on the criticality of the situation can enhance the sense of security that users feel towards ADAS.

Taking into account the types of interface that can be found in vehicles, Naujoks *et al*. [2019] emphasizes that visual interfaces are the most common. Han *et al*. [2018] conducted a study that examined how different types of buttons affect a *touch screen* interface, concluding that the shape, contrast and particularly size of the buttons significantly impact the usability of the interface. Furthermore, in terms of performance, Kaufmann and Riener [2018] assessed the ability of drivers to interpret information using five different speedometer styles (that is, classic, zoom, linear, bracket and digital) within a simulated environment. Initial findings indicated that traditional speedometers led to better performance, possibly due to the lower cognitive load required to understand the information.

Cognitive workload is a crucial aspect in the creation of vehicle interfaces [Li *et al*., 2020; Naujoks *et al*., 2019]. Designing interfaces that present information clearly and intuitively can help minimize driver distractions and improve road safety [Li *et al*., 2020]. In a simulation study, Li *et al*. [2020] examined the cognitive effort and visual demand required to interpret a visual interface that displays real-time information for safer driving, such as *brake slowly*. Data gathered from participants’ pupil responses showed a variation in demand depending on the scenario’s complexity and the task at hand. Naujoks *et al*. [2019] suggested a series of best practices or guidelines derived from the literature to aid in the design of various types of interfaces. They highlight the importance of providing clear and succinct information to reduce the driver’s mental workload.

3 Reseach Method

In this section, we introduce the method and its respective steps adopted in our study, as well as the ethical considerations.

3.1 Study design

Previous studies suggest that the application of the UCD cycle in designing vehicle notification systems has not been extensively explored. The use of personas and workshops for the development of notifications was reviewed in Lindgren *et al*. [2007]; Brinkley [2021]. Visual notification feedback was covered in Sun *et al*. [2021]; Naujoks *et al*. [2019]; however, the studies were conducted in a different context of our investigation. Recent investigations have aimed to improve road safety [Frison *et al*., 2019b; Li *et al*., 2019; Frison *et al*., 2019a] and minimize cognitive load when processing notifications [Kaufmann and Riener, 2018; Naujoks *et al*., 2019; Sun *et al*., 2021]. However, none of these studies have specifically examined the user experience with notification systems in situations involving the danger of collisions with motorcycles detected in a vehicle's blind spot.

Taking into account the literature gaps, three research questions (RQ) guided this study as can be seen in Table 1. To address the RQs, the study followed the four phases as shown in Figure 1.

Table 1. Research questions, focuses and methods

Research Question	Focus and Method adopted
RQ1) What are the relevant characteristics of the driver in the study domain?	**Focus:** uncover the relevant characteristics that impact the use of ADAS and drivers' behavior in risky traffic scenarios. **Methods:** Semi-structured interviews to collect data and personas to provide a perspective of end-users characteristics.
RQ2) What are the types of notifications that best meet the demands of the domain?	**Focus:** identify the different forms of notification that can serve the target audience considering the specificities of the domain. **Methods:** Co-design workshops and low fidelity prototype.
RQ3) Which type of notification requires less interpretation effort?	**Focus:** evaluate the adoption of the notifications by end-users. **Methods:** high fidelity prototype and user evaluation.

To answer RQ1, in the **first phase** (see Phase 1 Figure 1), the characteristics of the end users, their preferences about the use of ADAS, and their behavior in traffic were investigated using semi-structured interviews. The qualitative data gathered were analyzed, leading to the creation of personas that depicted the target audience of the study.

In relation to RQ2, the **second phase** involved organizing a co-design session aimed at producing concepts that aligned with the personas and also motivating the generation of novel ideas (see Phase 2 Figure 1). During the workshop, different types of notification were suggested through low-fidelity prototypes (i.e., paper prototypes). Further analysis of the prototypes revealed various alert styles (e.g., visual and auditory) and how these alerts could be utilized to notify drivers about the risk of colliding with motorcycles.

Taking into account the results of the workshop, in the **third phase** a unique proposal with different forms of notification was developed as a low-fidelity prototype (see Phase 3 Figure 1). The technical feasibility of implementing this prototype was discussed and then implemented as a functional high-fidelity prototype.

Finally, in the **fourth phase**, the high-fidelity prototype was used to answer RQ3 in an evaluation conducted with end-users (see Phase 4 Figure 1). The effort to interpret the different types of notification was the criterion for the evaluation.

The three studies involved the collaboration of five researchers with diverse backgrounds, as detailed: 2 Computer Engineering undergraduates with experience participating in ADAS development projects (called Researcher A and B); a bachelor's degree in mechatronics, a researcher in the area of vehicle safety (Researcher C); a design professional working in the area of prototyping interfaces and tangible products (Researcher D); and a senior HCI researcher with 15+ years of experience (Researcher E).

3.2 Ethical considerations

Studies involving drivers, especially those that seek to evaluate vehicle prototypes or driver assistance systems, require a careful ethical approach at all stages of the process. In this context, we highlight three distinct phases of study: user interviews, a co-design workshop, and evaluation of the final prototype. The evaluation protocol was assessed by the human ethics committee of *Centro Universitário Facens* and approved under CAAE 59612622.9.0000.5097.

Interviews and co-design workshop. During these phases, the confidentiality and anonymity of personal information collected were ensured, and minimize potential risks, paying attention to stress or discomfort that may be generated during the study.

Evaluation. In this phase, the safety protocols were followed using the appropriate safety devices, such as seat belts and helmets (for the motorcyclist), as well as using a low speed. Drivers were also asked for transparent and respectful feedback on their experience with the prototypes, encouraging open communication and valuing their opinions.

At all stages, participants were informed about the purpose of the research, explicitly informed about the risks and benefits provided by it. They were also informed about the type of data collected (mostly in audio format) and were asked to sign an Informed Consent Form in agreement with participation.

4 Understanding end-users characteristics

The initial investigation focused on exploring the characteristics of typical users within the domain. In this study, the domain consists of drivers who regularly navigate busy roads. Given the nature of the domain, semi-structured interviews were selected as the research method due to their flexibility, which allows researchers to seek clarifications during the interview process Sharp *et al*. [2019]; Lazar *et al*. [2017]. Three researchers participated in this study, specifically Researcher A and Researcher B (see profiles in Section 3).

However, representing user data from interviews in a fully textual form can be challenging. To address this issue, the personas technique was used to represent the typical end-users of the explored domain. The advantage of using personas is that they present user characteristics in a way that makes potential users easier to visualize Sharp *et al*. [2019]. A persona is a fictional character that represents a group of users and is developed through qualitative research, highlighting the most relevant aspects of the audience Cooper and Reimann [2003].

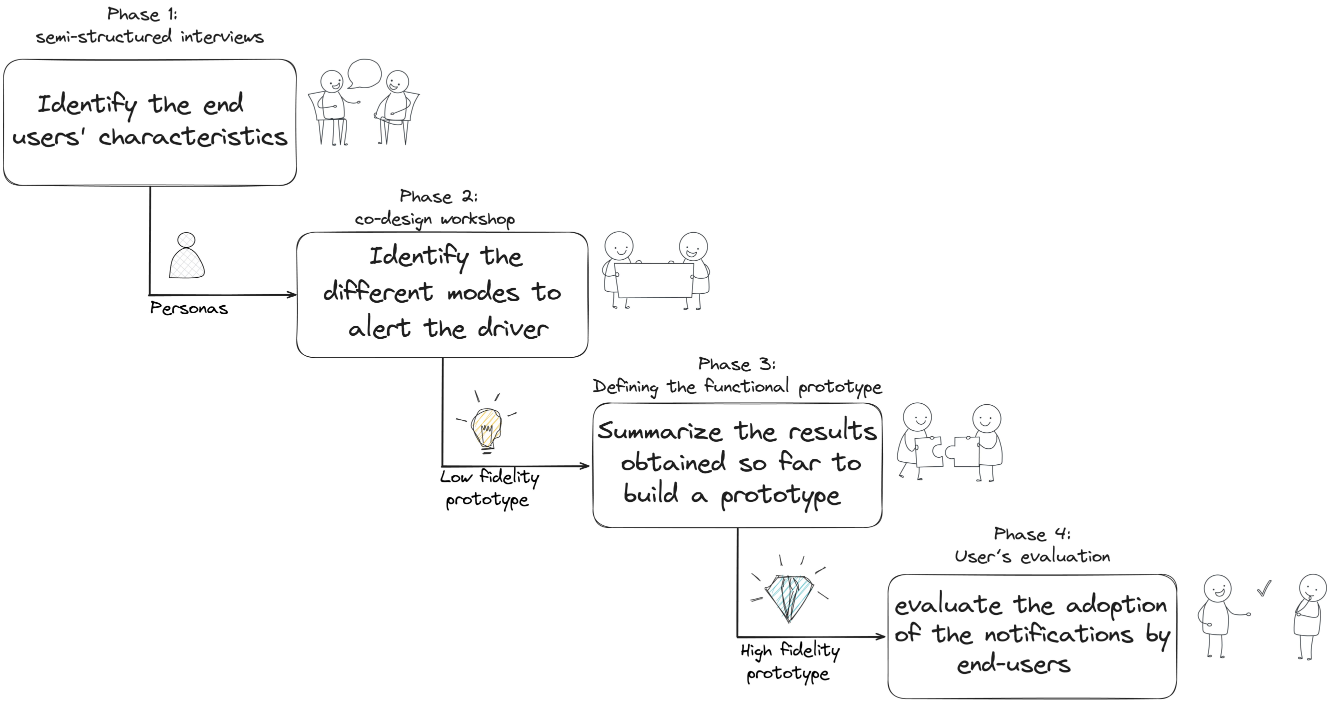


Figure 1. Method phases

The conception of the interview instrument, the data collection procedures, the data analysis, and the results are presented, along with the personas developed in this study.

4.1 Data collection instrument

The interview instrument was developed based on two studies focusing on drivers' user experience with ADAS.

The first study discusses the *DAUX Framework*, which serves as a systematic structure for defining and evaluating UX in the context of automated driving challenges [Frison and Riener, 2022]. This framework outlines the process of identifying essential requirements for UI (User Interface) development and assessing UX by considering three key factors: behavior, product, and user experience. The *DAUX Framework* consists of five interconnected layers: (a) Technical Restrictions (defining degrees of automation based on the SAE J3016 standard [SAE International, 2018]); (b) Driving Automation User Interface (related to the interfaces in advanced vehicles that facilitate easier movement); (c) Psychological Needs (challenges and requirements users face when interacting with interfaces, primarily related to cognitive factors such as distractions or fatigue); (d) Affect (positive or negative conditions that influence user experience in terms of comfort and safety, which can result from system failures or personal issues); and (e) User (aspects related to the use of the product, including perceptions, features used, challenges encountered, and interactions with the system).

The second study describes a survey conducted among drivers in Spain and Portugal, focusing on observing users' actions while driving in traffic and their interaction with ADAS [Paiva *et al.*, 2021]. The findings analyze the key characteristics and actions of ADAS necessary to ensure driver safety and convenience. The survey questions addressed eight themes: (i) general characteristics of drivers and their behavior in traffic; (ii) work-related stress (investigating scenarios where ADAS might cause discomfort to drivers); (iii) drivers' lifestyle (gathering information about geographical location and other factors affecting driving experience); (iv) technological features of vehicles and their usage; (v) driving behaviors (analyzing how drivers interact with ADAS and how it influences their behavior in traffic); (vi) distractions while driving (exploring the impact of ADAS on driver attention); (vii) driving stress (gathering data on situations where drivers experience stress); and (viii) driving assistance (compiling information on ADAS resources and their effectiveness in assisting drivers).

Considering the two studies, our interview instrument included demographic questions and 17 additional questions divided into three categories, as shown in Table 2. The table also indicates which study was used in the conception of each question. The *Driving Style and Behavior* category pertains to the participants' behavioral traits while driving in traffic. This includes aspects such as their typical actions, like checking vehicle mirrors, their accident history and the circumstances surrounding those accidents, familiar driving locations, driving speeds, and whether their vehicles are equipped with ADAS. The *Notifications* category addressed participants' engagement with assistance systems, covering the types of ADAS they used, their preferred notification format, the ideal timing for alerts, and their willingness to modify ADAS features. Lastly, the *Scenarios with a Motorcycle* category explored situations involving a motorcycle, collecting information on how participants reacted in three distinct scenarios where a motorcycle passed through a vehicle's blind spot. Each scenario provided specific information regarding the motorcycle's approach, including its speed and distance.

Before conducting the interviews, a pilot test was carried out with two participants (who were not included in the final

Table 2. Interview questions and the literature used for elaboration of each question - **DAUX framework layers:** (a) Technical Restrictions; (b)Driving automation user interface; (c) Psychological needs; (d) Affect; (e) User. **Survey themes:** (i) general characteristics of drivers and their behavior in traffic; (ii) stress related to work; (iii) drivers' way of life; (iv) technological features of vehicles and their utilization; (v) driving behaviors; (vi) distractions while driving; (vii) driving stress; and (viii) driving assistance.

ID	Questions	DAUX framework [Frison and Riener, 2022]					Survey [Paiva *et al.*, 2021]							
		(a)	(b)	(c)	(d)	(e)	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	Driving Style and Behavior													
Q1	Does your vehicle have ADAS? Do you use it or do you leave it disabled?	X	X	X	X					X				X
Q2	On average, how many kilometers do you drive per week?					X	X		X					
Q3	About your speed in traffic, how do you rank your speed with the speed of other drivers?					X	X				X			
Q4	Have you ever been in a traffic accident? If so, do you remember how it happened and who was involved?					X			X		X			
Q5	How are the places you are used to driving to, are they busy or calm?					X	X		X		X		X	
Q6	Do you usually check your mirrors during maneuvers such as lane changes, or when entering another lane? Describe the situation.			X							X			
Q7	Do you have passengers while you're driving?					X	X		X					
	Notifications													
Q8	When do you find it useful to have a notification from an ADAS?			X		X	X	X						X
Q9	Which aspects of ADAS would you like to change? Like the timing or the form of being notified.			X	X					X				X
Q10	How often and when would you like to be aware of what is happening in traffic?		X										X	X
Q11	Which way would you consider most comfortable or enjoyable to be alerted? You can be creative about how you will be notified.	X			X					X		X		X
Q12	Do you have the habit of listening to music or the radio while driving?			X		X			X					
Q13	Do you distract yourself while driving? How often? How do you do it?			X		X						X		
Q14	What helps you to avoid distractions while driving?			X		X						X		
	Scenarios with Motorcycles													
Q15	You are driving at 70 km/h, and you want to make a lane change, you look in the rearview mirror and notice a motorcycle slowly approaching about 40 meters behind you. What do you do?			X		X	X				X	X	X	
Q16	Same situation, but when you check your rearview mirror you see a motorcycle approaching fast, about 60 meters behind you. What do you do?			X		X	X				X	X	X	
Q17	You're traveling at 60 km/h and you see a motorcycle, you accelerate to pass it and return to 60 km/h. After 3 seconds you decide to change lanes, you look in the rearview mirror and don't see the motorcycle anymore, what do you do?			X		X	X				X	X	X	

sample). The final version of the interview instrument was obtained after some adjustments in the question descriptions.

4.2 Interviews Execution

The participants were recruited from the *Centro Universitário Facens* community (i.e., professors, students, and staff). They were selected based on specific criteria: being users of ADAS, regularly driving in busy traffic, and being at least 18 years old. A total of 11 volunteers, consisting of 5 males and 6 females, agreed to participate in the study. The interviews were individually conducted by researchers A and B (see profiles in Section sec:method) in an office at *Centro Universitário Facens*.

During each interview, participants were informed about the purpose of the investigation and their rights, which were ensured through strict ethical guidelines (see Section 3.2). After signing the consent form, the participants answered the questions (see Table 2), and each interview lasted approximately 40 minutes. In total, 4 hours and 38 minutes of audio were recorded.

4.3 Data Analysis and Results

The interview recordings were first transcribed into a textual format. Researchers A and B then independently performed a qualitative analysis using the closed coding technique [Strauss and Corbin, 1998]. This method involves exploring qualitative data and assigning predefined codes (i.e., from a codebook) to text segments to extract meaning. Identifying patterns based on code groups leads to a more insightful interpretation of the findings Strauss and Corbin [1998]. Researcher E (see profile in Section 3) also participated in the analysis of data patterns.

The codebook used in the study included four categories of codes related to: (1) *notifications activated by ADAS* and their outcomes, including whether the alerts induced comfort or discomfort, whether they distracted drivers, and the type of notification (e.g., visual, audio, haptic); (2) *driving behavior*, distinguishing between conservative and aggressive drivers; (3) *driver context characteristics*, i.e., vehicle usage, road types frequented, and the presence of passengers; and (4) *user experience aspects*, i.e., factors that affect their experience and interactions with ADAS.

Based on these four aforementioned groups, the findings indicated that drivers exhibited either aggressive or conservative behaviors, typically navigating through heavy traffic with passengers on board. The analysis also revealed that the nature of ADAS alerts significantly influences the user's driving experience. The findings showed that participants preferred receiving accurate alerts in situations involving risky actions, which helped them stay aware. Additionally, participants reported a preference for audio alerts as the most efficient and noticeable compared to visual and haptic notifications. However, they noted that sound notifications might become less noticeable with frequent use over time. As an alternative, participants suggested visual notifications, which they believed could provide sufficient information to help drivers understand the situation. However, they emphasized that the effectiveness of visual notifications depends on their placement and could potentially distract drivers from focusing on the road.

4.4 Personas

In our study, qualitative personas were used to describe characters that offer insight into end-users, i.e., drivers. These qualitative personas were developed through small-scale qualitative research, specifically using interview data Cooper and Reimann [2003]; Sharp *et al*. [2019]. Since we followed a UCD approach, personas played a crucial role in enhancing the understanding of end-users and fostering empathy among both the project team members and the end-users themselves Cooper and Reimann [2003].

To provide more detail about personas, we reviewed the analysis results, focusing on four categories of coding (*notifications activated by ADAS*, *driving behavior*, *driver context characteristics*, and *user experience aspects*). These categories encompass the key features of the personas within our domain.

Data in each category were reviewed to ensure that all relevant aspects of persona construction were included. Two researchers then individually developed personas based on the data, after they had a meeting to discuss and select the most essential descriptions of persona characteristics presented in the personas previously elaborated. As a result, two personas were created. These personas were later reviewed by a third researcher. The final versions of the two personas are presented in Figure 2.

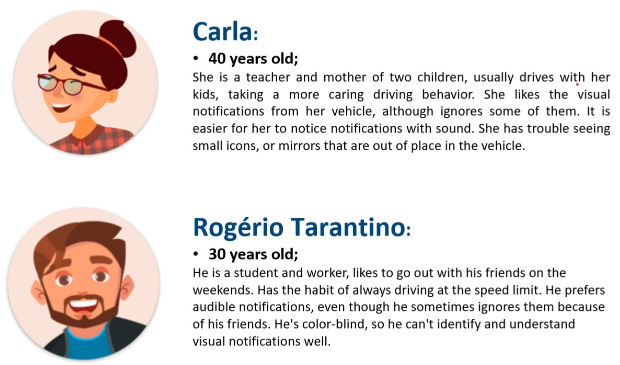


Figure 2. The two personas elaborated

”Carla” represents drivers who prioritize safe driving practices, being careful and vigilant on the road. She values not only her own safety but also that of passengers and other road users, such as pedestrians and fellow drivers. Although she remains observant of her surroundings, she tends to lose focus when passengers engage her in conversation or when driving on familiar roads. ”Carla” prefers visual alerts but may overlook them due to her vision problems (i.e., myopia).

The persona ”Rogério Tarantino” embodies individuals who exhibit more aggressive driving behaviors, often exceeding speed limits and neglecting traffic signs. He is easily distracted by the presence of friends and tends to be inattentive to his surroundings while driving. Additionally, ”Rogério Tarantino” represents drivers with visual impairments, such as color blindness, which affect their ability to interpret visual signs. He prefers auditory and haptic alerts, but struggles to interpret them when distracted by conversations, music, and the poor road conditions that he often encounters.

From the descriptions above, we observe that ”Carla” and ”Rogério Tarantino” share similarities with the personas suggested in Lindgren *et al*. [2007]. Unlike ”Kristina” and ”Camila,” ”Carla” demonstrates a more cautious driving style. However, both ”Carla” and ”Rogério Tarantino” display a tendency to become distracted by external stimuli, a characteristic shared with ”Mats” in the personas. There are also parallels between our personas and those outlined in Brinkley [2021] with respect to visual impairment. However, our personas provide more detailed insight into notification preferences and driving behavior, which are better aligned with the objectives of our study and, consequently, better help in the design of ADAS notifications in our study.

5 Co-designing the alert system

As discussed in Section 2.2, the literature has shown a demand to develop ADAS solutions that not only improve safety but also that are easy for users to interpret. Although the initial study resulted in the creation of personas, this information alone is insufficient for proposing notifications due to the technical complexities related to human memory load requirements. Therefore, it is crucial to gather input from a diverse group of users, both technical and non-technical, when designing the notification system.

To meet the need for more user-oriented ADAS, a co-design *workshop* was organized with the participation of Brazilian drivers. The main goal for the participants was to encourage them to create solutions for warning systems, using various forms of notification regarding the identification of a motorcycle in the vehicle's blind spot. The co-design workshop involved five researchers: Researchers A, B, C, D and E (see profiles in Section 3).

5.1 Participants

To obtain different perspectives from vehicle drivers and ADAS users, individuals residing in Sorocaba and the São Paulo region were invited based on the network of the researchers. The participants were divided into two complementary profiles: common users, who were drivers who regularly navigate busy roads and at risk of accidents involving motorcycles, and technical users, who had the same driving profile, but had some technical knowledge about vehicle systems (such as engineers or vehicle systems technicians). Although both profiles included vehicle drivers, they offered complementary viewpoints, focusing on both practical needs and technological considerations.

In total, 9 individuals participated in the workshop, 4 from the group of common users and 5 from the technical users. On the day of the workshop, participants completed a profile questionnaire that collected the following data: type of CNH (National Driving License) and how long they had held their license; type of vehicles they owned or regularly drove (to identify the ADAS capabilities of their vehicles); and their routine with regard to the period of the day they typically drove (to check if they drove during peak traffic hours). The participants (N = 9) were divided into 3 groups, each consisting of 3 participants. Two of the groups had 2 technical users and 1 common user, while one group had 2 common users and 1 technical user. It is important to note that none of the participants had prior involvement in the research (i.e., the project). Table 3 presents the participants' profiles categorized into groups identified by A, B, and C.

5.2 Workshop materials

For the co-design process, the low-fidelity paper prototyping technique was adopted. This approach was chosen because it allows participants to visualize solutions quickly while allowing them to interact with the object under construction Sharp *et al*. [2019]. To give participants a more realistic view, three perspectives of a vehicle were printed (see Figure 3): one internal view, showing the dashboard, seats, and doors; and two external perspectives, one from the driver's side and another from above. These perspectives were posted on the walls near the group tables, and each group worked with their own set of perspectives.

Additionally, each group received a box containing materials such as pencils, pens, markers, and post-its. The selection of these materials was inspired by the PICTIVE technique [Muller, 1991], which uses basic materials to facilitate idea generation and the creation of low-fidelity prototypes. The box also included cards with icons representing possible types of notifications for the user (Figure 3). The use of icons was inspired by the CARD technique [Tudor *et al*., 1993], a variation of PICTIVE, which uses cards with visual elements. We included a card labeled "vibration" to represent haptic interaction, as this term is more familiar to users. Additional "Other" icons were provided (see Figure 3) so participants could suggest other types of notification they deemed appropriate. Each form of interaction had an icon and a color that identified it. To participants take notes , the box also contained post-its with colors related to each alert type.

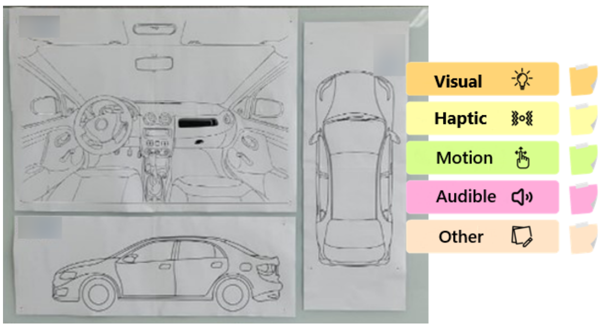


Figure 3. Card notification types and perspective templates.

Furthermore, the box included papers with descriptions of the two *personas* resulting from the work described in Section 4. These papers featured the same illustrations as those shown in section 4.4. The purpose of using personas was to establish an empathetic relationship between the participants and the target audience.

5.3 Workshop execution

The workshop was conducted at *Centro Universitário Facens* in a room containing tables for discussions in groups.

Presentation of the workshop. First, an overall presentation of the project and the workshop agenda were delivered to the participants[1]. The agenda for the co-design conduction was divided into two stages: producing three individual prototypes, one for each group, and developing a unified prototype that integrates the concepts from all three groups. Participants were then asked to read and sign the Free and Informed Consent Form (ICF) (all 9 participants signed the document). Afterward, they filled out the profile questionnaire on paper (see data in Section 5.1).

Warm-up activity. Before starting the main activities of the workshop (i.e., the prototyping sessions), a 15-minute warm-up was carried out so that participants could understand the dynamics of building the prototypes. Participants were encouraged to develop a simple interface for a music mobile application (such as Spotify). The aim was to employ a well-known application to help participants become at ease with tools such as markers and icons. A paper template for a mobile device screen was supplied for group prototype development.. The participants also conducted discussions about their decisions on the prototype conception.

Creation of the three prototypes. After the warm-up, the groups began constructing their three low-fidelity prototypes. The researchers emphasized again that the goal was to design a warning system that addressed the presence of motorcyclists in the vehicle's blind spot. The groups had approximately one hour to discuss ideas and develop solutions using the perspectives posted on the walls.

Figure 4. Co-design activities.

Consolidation of the three prototypes. Finally, the three groups were asked to collaborate in creating a new prototype, consolidating the ideas from the previous prototypes and incorporating any new ideas that may emerged. At the end of this phase, the 9 participants explained their concepts for the unified prototype to the researchers.

The four prototypes produced during the co-design session were photographed. Furthermore, all participants' speeches during the presentation of the created prototypes were audio recorded.

[1] Programa Rota 2030 - Facens. Available at: . Last access: January 28, 2025

Table 3. Workshop participant profiles

Grupo	Id	Profile	Occupation	CNH	Driver's license time	Traffic	Gender	Age
A	P1	Regular user	Psychologist	B	24 years	Moderate traffic	F	40+
	P2	Technical user	Mechanical Eng.	B	22 years	Heavy traffic	M	31-40
	P3	Technical user	Researcher	B	01 year	Moderate traffic	M	18-30
B	P4	Regular user	Electrical/Electronic Eng.	D	22 years	Heavy traffic	M	31-40
	P5	Technical user	Researcher	B	06 years	Heavy traffic	M	18-30
	P6	Regular user	Mechanical Eng.	AB	30 years	Moderate traffic	M	40+
C	P7	Technical user	Researcher	AB	01 year	Heavy traffic	M	18-30
	P8	Technical user	Electrical/Electronic Eng.	AB	20 years	Heavy traffic	M	40+
	P9	Regular user	App driver	C	38 years	Heavy traffic	M	40+

5.4 Analysis and Results

The four low-fidelity prototypes (see Figure 5) were analyzed together with audio recordings of participants. Researchers A, D and E (see profile in Section 5) participated in the analysis, following the procedures described below.

First, Researcher A explored the three prototypes developed individually by the 3 groups. For each prototype, the type of notification was identified (see Figure 3) and its placement in the vehicle was recorded in a spreadsheet. Then, Researcher A listened to the audio recordings to understand the context in which the alert would be used, according to the prototype creators, and whether there was redundancy in the alert format (sound, visual) for the same accident risk scenario. The same procedure was followed for the consolidated prototype created by all participants.This step generated the intermediate result (see Table 4) that reports the different notification types proposed as solutions, how the notification works (notification in action) and which notification is used in redundancy to alert drivers about the motorcycle in the blind spot.

After this, Researcher A presented the results to Researchers D and E, and together they consolidated the data from the four prototypes, generating a summarization of the resources as presented in Table 5. These results were used to develop the alert system, which will be discussed in the following section.

5.5 The use of the personas in the co-design

By observing the prototypes produced in the workshop, it became evident that personas provided valuable insights for the participants; besides, they aimed the participants to not limite the generation of new ideas. This practice has demonstrated its ability to foster empathy and comprehensively consider end-user needs [Cooper and Reimann, 2003].

The preference for visual notification can be seen by examining the personas (see Figure 2) and this preference was reflected in the prototypes proposed by the groups (see Table 4); all groups incorporated some form of visual notification into their alert systems, varying in intensity and location of application in the vehicle. However, the personas also suggested that this type of alert may not be effective in certain specific contexts. This gap was identified by the designers and addressed through the introduction of redundancies in the alert mechanisms, with the predominant inclusion of audible alerts as a secondary form of communication (see Table Table 4).

Many of the proposals considered positioning notifications in strategic locations in the vehicle, such as the rearview mirrors, spot frequently used by drivers (see Table Table 4). Additionally, the groups took into account informing about the level of collision risk based on the motorcycle's distance and speed, as well as warning of hazardous maneuvers, as illustrated in the suggestions put forward by Groups B and C (see Table 4). Such notifications were specifically tailored to meet the needs of the persona "Rogerio Tarantino" (see Figure 2).

Finally, it is noteworthy that participants were not restricted to the types of alerts mentioned by the *personas*, having also proposed the use of haptic or mechanical alerts (as indicated in *Others* in Table 5). Workshop participants recognized the importance of a holistic approach to alert design, including a thorough analysis of the context of use to ensure that alerts would be effectively perceived and understood by users in various situations and environments. These discussions and insights contributed significantly to the development of more robust and user-centric prototypes.

6 Development of the alert system

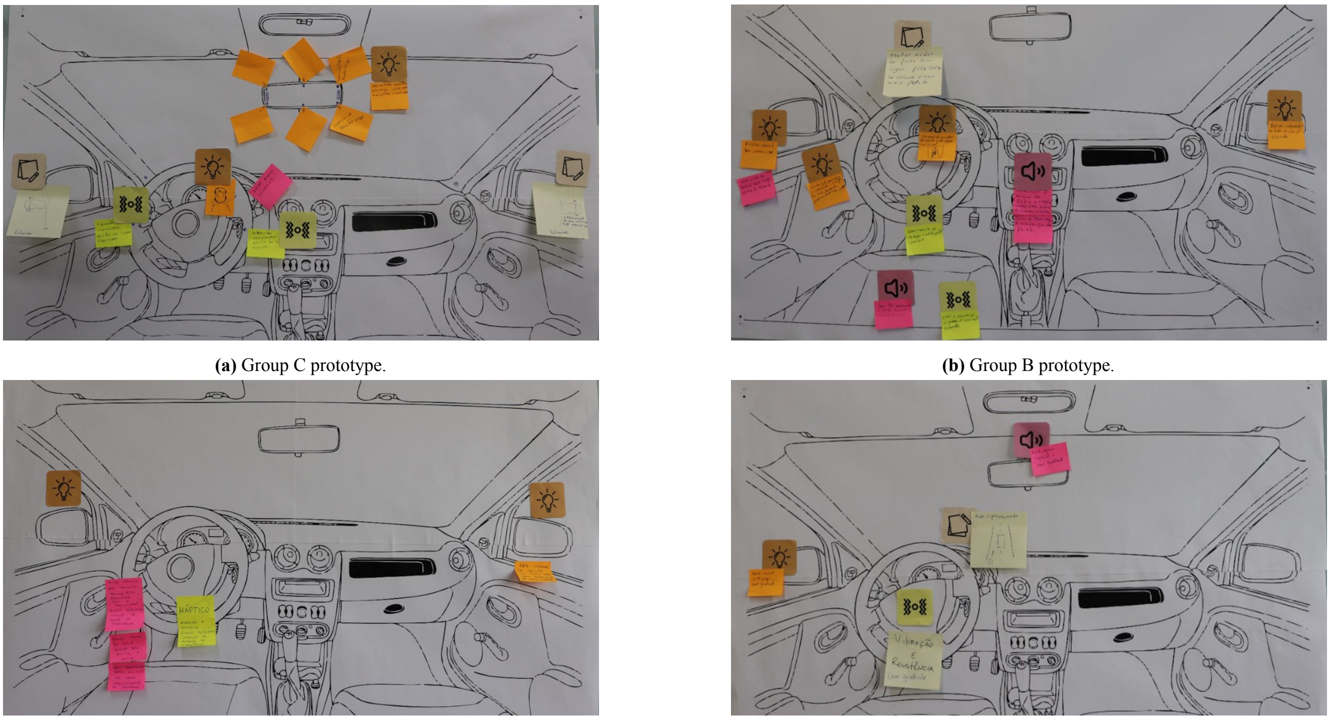
Considering the consolidation of the 4 prototypes, Researchers A, D, and E had another meeting to build a low-fidelity prototype that put together several features described from the prototypes. The researchers considered the results from Table 5 and also the four prototypes created during the workshop (see Figure 5), which helped in better understanding of the placement of the notification elements (visual, audible, and haptic). No new types of alert were included; only the results obtained in the prototypes were considered. As a result, the prototype of Figure 6 was produced.

After developing the final low-fidelity prototype, the researchers presented the solution to the project group. ADAS development specialists were invited, namely Researchers B and C, along with another vehicle systems technician. The main idea was to verify the technical feasibility of implementing the proposed notifications in a functional prototype. This step was important because the project already had a functional module (without interfaces) that produced signals when a motorcyclist was detected in the vehicle's blind spot. Furthermore, the feasibility of implementation of the features would be discussed according to the equipment and technologies currently available.

Considering technical feasibility, the researchers decided that visual and haptic notifications would be implemented in the first version of the alert system. For the visual type, the team selected form B (see Table 5), as it could be implemented on a *tablet* and attach it to the vehicle dashboard. For haptic notifications, the forms E, F, and G were chosen

Table 4. Resources proposed by each group in their low-fidelity prototypes

Group	**Place in vehicle**	**Notification type**	**Context/Explanation of use**
A	Internal rearview mirror	Visual	Internal rearview mirror has a few dots that change color as the motorcycle approaches. It also has two bars on the side to indicate which side the bike is coming from.
	Instrument Panel	Visual	On the dashboard, in association with the car's own tool (there is a miniature of the car on the tool panel), it will indicate which way the motorcycle is coming by means of arrows, the arrows having gradient colors according to the approach of the motorcycle.
	Instrument Panel	Sound	(HAS NOT BEEN EXPLAINED) This notification will act in conjunction with the others, alerting the driver in a gradient way.
	Steering wheel	Haptic	The steering wheel will vibrate according to the side the motorcycle is approaching, and will only notify you when there is a motorcycle in your blind spot.
	External rearview mirror	Other	External rearview mirror is divided into two parts, one fixed and one movable. The fixed part allows the driver to see what is happening on the sides of the car, as they normally do. The movable part allows the driver to see the blind spot. This part of the mirror, which detects motorcycles in the blind spot, will follow the motorcycle as long as it is out of its field of vision.
B	External rearview mirror	Visual	When it detects a motorcycle in the blind spot, it turns on a light to tell the driver which side the vehicle is coming from and how far away it is by means of gradient colors.
	Driver's door	Visual	Through peripheral vision, the driver receives information about the distance to the motorcycle via an LED strip on the driver's door. The strip changes its colors and the position of the LEDs according to the distance from the motorcycle.
	Instrument Panel	Visual	Indicates on the panel the side and distance the motorcycle is approaching the car (using a map to symbolize the whole context).
	Steering wheel	Haptic	(HAS NOT BEEN EXPLAINED) When a motorcycle is detected in the blind spot, the steering wheel will vibrate, but it will be a weak vibration (it does not indicate the direction it is approaching).
	Driver's seat	Haptic	(HAS NOT BEEN EXPLAINED) If the driver is too distracted, the seat will vibrate to return their attention to the traffic.
	Vehicle interior	Sound	Sound notification with 3D audio (surround sound), which indicates the side and distance the motorcycle is coming from.
	Driver's door	Sound	(HAS NOT BEEN EXPLAINED) The audible notification comes from the side, and is only activated when you are going over 40 km/h.
	Vehicle media panel	Sound	When a motorcycle is detected in the blind spot and the driver intends to perform a lane change maneuver, the radio sound is interrupted/lowered so that the driver can pay attention to other notifications.
	Steering wheel	Other	When making a lane change maneuver without indicating the turning signal, the steering wheel will stiffen, forcing the driver to indicate their maneuver.
C	External rearview mirror	Visual	LED blind spot indicator with gradient colors, indicating the distance from the motorcycle.
	Vehicle interior	Sound	Sound warning that increases the volume and/or frequency of the notification when a motorcycle is approaching, or when it detects the intention to change trajectory (lane)/ Reduces the sound of the radio and emits the warning/ Sound is emitted from the same side as the obstacle (surround).
	Steering wheel	Haptic	Vibration and stiffness when a change in trajectory is detected and there is a motorcycle in the blind spot.
General	External rearview mirror	Visual	Simple visual alert with gradient colors, changing colors to indicate the distance from the bike.
	Steering wheel	Haptic	Vibration and steering wheel resistance with gradient vibration (weak vibration until it gets stronger), will change as the motorcycle approaches.
	Vehicle interior	Sound	Spatial sound alert with gradient.
	Instrument Panel	Other	Map on the panel with the positioning of the car and motorcycle, and the distance between them.



(a) Group C prototype. **(b)** Group B prototype.

(c) Group A prototype. **(d)** Prototype created by all the groups.

Figure 5. Low-fidelity prototypes proposed.

Table 5. Consolidated co-design workshop results.

Notification type	Usage in the vehicle
Visual	**A)** Indicator lights on the exterior rear-view mirror display the distance between the motorcycle and the car: red for 500 mm, orange for 1000 mm, and yellow for 1500 mm. Additionally, a bar on the sides indicates the approaching side of the motorcycle.
	B) Shows a map of the car and motorcycle on the dashboard. It indicates the direction and side in which the motorcycle is approaching and the distance is indicated with gradient colors in the motorcycle symbol or by arrows.
	C) Light in the exterior rear-view mirror that indicates when there is a motorcycle in the blind spot and how far it is from the car (with gradient lights).
	D) LEDs on the driver's door that indicate when there is a motorcycle (it starts to glow) and how far away it is (using gradient colors). The driver sees this notification through their peripheral vision.
Haptic	**E)**The steering wheel starts to vibrate when a motorcycle is detected, with the vibration coming from the direction of the motorcycle. The vibration starts weak and gradually becomes stronger.
	F) Faint vibration in the steering wheel indicating that he has encountered a motorcycle in his blind spot.
	G) The seat vibrates, causing the driver to turn their attention to the traffic, activated if the driver is distracted.
	H) Vibration and resistance of the steering wheel when a lane change is detected, a change that has been made without indicating the signal. It would be activated in situations where there is a motorcycle in the driver's blind spot.
Audible	**I)** Acoustic notification with gradient (indicating distance) that works in conjunction with other types of notification. It is only activated when it detects a motorcycle.
	J) 3D audio notification from the driver's cabin. Through the sound, it will be possible to identify the direction and distance of the motorcycle (the sound accompanies it).
	K) Reduction of radio audio to alert the driver to the proximity of a motorcycle in their blind spot. Activated when you intend to make a maneuver. The sound will come from the same side as where the motorcycle is coming from.
Others	**L)** In the external rear-view mirror, a movable part is inserted that observes and identifies motorcycles in the blind spot. When identified, it follows the motorcycle to show its location to the driver.

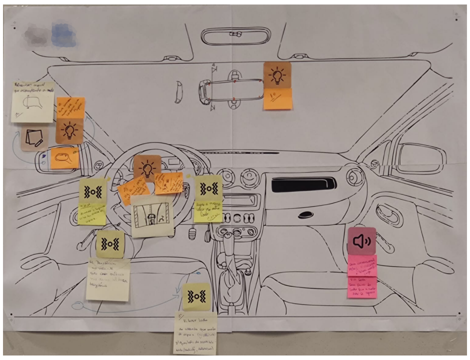


Figure 6. Prototype consolidated by researchers.

(see Table 5). Other types of notification were excluded from the first version, as their implementation depended on the approval of the partner company that supplied the test vehicle, which could take a long time until approval.

Researchers A and B implemented visual and haptic notifications. Both implementations relied on collision risk signals sent by the vehicle's external sensors and installed functional modules. The criticality of the situation for both types of notification varied according to the approach of the motorcycle within the 30-meter range established by the standard, which specifies this distance for the notification of approaching vehicles [ISO Central Secretary, 2008].

For the visual alert, a graphical interface was developed running on a Samsung Galaxy S6 Lite, model SM-P615, 10.4 inches. Figure 7 shows three versions of the interface that inform the driver of risk situations. The interface displays information about the distance of the motorcycle from the vehicle (center of the interface), the criticality of the situation using colors and icons (left side), and the vehicle's current speed (right side).

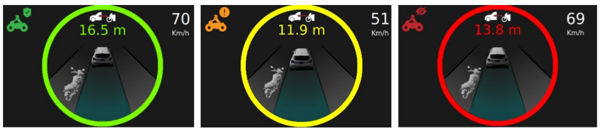


Figure 7. Graphical user interface for warning system.

For haptic warning, micromotors were installed in the driver's seat and steering wheel. When the system detected a motorcycle at risk of collision, a signal was sent to an Arduino component[2] connected to the motors, causing the seat and steering wheel to vibrate. The intensity of the vibration indicated the level of collision risk and varied depending on the movement of the motorcycle.

7 Proposal Evaluation

The evaluation of the alert system, which included visual and haptic notification formats, was conducted on the internal street circuit of the Facens University Center (as described in Section 7.1). The evaluation protocol followed all vehicular safety recommendations and was planned and executed following the recommendations of Lazar *et al*. [2017]. Researchers A, B, C, and E were responsible for all evaluation application (see profiles in Section 3). It is important to note that the participants in this activity were not the same users as those of the *workshop*.

[2]Open-source platform for programming electronics and microelectronics [Badamasi, 2014]

7.1 Planning

The evaluation aimed to collect participants' experiences and interpretations of the visual and haptic alerts emitted from the proposed system. The focus was on evaluating whether participants could perceive the presence of motorcycles in the blind spot without much effort to interpret the alert. Materials and procedures were prepared to perform the evaluation, as described below.

A profile questionnaire was developed to collect participant data, including age, sex, type of driver's license, time holding a driver's license, and type of ADAS presented in the participants' vehicle. The Informed Consent Form (ICF) was prepared in paper format, as approved by the ethics committee. Three scenarios were evaluated: two using the notification formats individually (either visual or haptic), and a third using both simultaneously. The scenarios simulated real situations in which a motorcycle passes through the blind spot to trigger the alert system.

The two types of notifications were installed on a test vehicle, a 2019 Jeep Renegade. For visual notification, a *tablet* was attached to the vehicle dashboard (see the description of *tablet* in Section 6). A motorcycle, a Yamaha/YBR150 Factor E model, was also used to simulate the motorcycle passing through the blind spot.

To data collection, *think aloud* and *Situation Awareness Rating Technique* were adopted. In *think aloud* method, participants are encouraged to describe their thoughts out loud Lazar *et al*. [2017]. In this study, the method would allow researchers to better understand the interaction of the participant with the notification system. *Situation Awareness Rating Technique* (SART) is a self-report technique that collects data on the awareness of the situation of users when interacting with an artifact [Taylor, 2017]. SART has been widely used to evaluate user interaction in automotive and industrial systems [Sun *et al*., 2021; Satuf *et al*., 2016]. The instrument consists of a questionnaire with nine questions divided into three components that include (D) demands on the user's attention resources, provision of (S) supply of attention resources, and (U) understanding of the situation. Each component has questions that report a different dimension of situation awareness. Table 6 presents the details. Each dimension of SART is evaluated on a seven-point scale, with one being the lowest and seven the highest.

In addition to the materials previously described, a script was also prepared followed by the researchers. Two project researchers, who were not involved in this study, participated in a pilot test, which confirmed that the procedures and materials could be used as originally developed.

7.2 Conduction

The invitation to participate in the study was sent by email messages to professors and students at the Facens University Center. This allowed greater convenience for participation as participants were regularly present on campus. Twenty users agreed to participate in the study, with ten identified

Table 6. SART Components, Perspectives, and Questions

Dimension	Questions
(D) Demands on the user's attention resources	
(D1) Instability of the situation	How unstable was the situation? Was the situation highly unstable and likely to change suddenly (High) or quite stable (Low)?
(D2) Complexity of the situation	How complicated is the situation? Is it complex with many interrelated components (High) or simple and straightforward (Low)?
(D3) Variability of the situation	How many variables are changing in the situation? Are there a large number of factors varying (High) or are there few variables changing?
(S) Supply of attention resources	
(S1) Vigilance	Did the alarm interface allow you to be vigilant? Did it allow you to follow the sequence of events, predict the evolution of the situation, and be ready to act (High), or did the alarm interface induce a low state of awareness about the situation (Low)?
(S2) Attention concentration	How was your attention concentrated on the situation? Were you focused on the situation and following its evolution (High) or were you distracted between the situation and other occurrences around you (Low)?
(S3) Attention division	How was your attention distributed in the situation? Did the alarm interface allow you to concentrate on the most relevant aspects of the situation (High) or did it induce you to focus on just one (Low)?
(S4) Available mental capacity	How much effort did you have to make to understand the situation? Did you have to make a lot of effort to understand the situation (High) or did you have no difficulties understanding (Low)?
(U) Understanding of the situation	
(U1) Quantity and quality of information	How much information did you receive during the scenarios? Did you receive it and were able to understand well (High) or did you understand very little (Low)?
(U2) Familiarity with the situation	How familiar are you with this type of scenario? Do you have a lot of experience with situations of this type (High) or is it a completely new situation (Low)?

as male and ten as female. The selection criterion was to have regular driving experience (at least one year of driving license). The ages of the participants ranged from 18 to 40+ years. Regarding ADAS experience, 7 participants reported having no experience, 12 had some contact with visual features like a rearview camera, and only one participant had previously used a visual blind spot alert system (a feature that illuminates a light on the dashboard). None of the participants had experienced haptic notifications in ADAS.

The study was conducted in a semi-controlled environment on campus during periods of low traffic (holidays and weekends) on a one-way street circuit approximately 840 meters long. Figure 8 provides an overview of the internal route on the Facens campus. It is worth noticing that this route allows the driver to pass throughout the campus. During the study, the vehicle's driving speed varied between 20 and 30 km/h. The study followed all current safety protocols, such as the use of seat belts and helmets for motorcyclists. Each participant drove the vehicle for three laps around the circuit, considering the three scenarios described in the planning. In the first two laps, the participant experienced the alert system with visual or haptic notifications separately. To prevent one notification from influencing the other, participants were divided into two groups: one group started with the visual notification followed by the haptic, while the other group experienced them in reverse order Lazar *et al*. [2017]. In the third lap, both notification formats were applied simultaneously.

Initially, the participant was informed about the objective of the evaluation and its details (number of laps around the circuit, types of alert notifications under evaluation, and explanations about the functioning of the used vehicle). Subsequently, the participant signed the ICF and completed the profile questionnaire. The participant was then informed that the test motorcyclist would overtake them to trigger the system's notifications. For safety reasons, the participant was warned before the evaluation started about overtaking and triggering the notification on each circuit lap. This is intended to prevent the participant from being agitated and causing a collision risk. However, no warning was issued from the researchers when the notification occurred, allowing the participants to have a more realistic environment while driving. Participants were instructed to use the *think aloud* protocol while driving and interacting with notifications. During each lap, the motorcyclist (Researcher D) simulated overtaking maneuvers by passing through the blind spot. There was an average of six overtakes per lap, depending on the driving profile of the participant. When the alert system detected the motorcyclist, the respective notification type was activated according to the criticality of the scenario. At the end of each lap, participants completed the SART questionnaire on paper for a particular notification, i.e., visual and haptic, or for the combined notifications.

Figure 8. Campus one-way street circuit (route used in the study in blue color)

7.3 Analysis and Results

Table 8 presents the raw data collected from the SART instrument separated by the three SART components (D, S, and U - see Table 6). The decision to separate the components is because the literature recommends that they be evaluated

Table 7. SART Interpretation

Dimensions	Positive	Negative
(D1) Situation Instability	<=3	>=5
(D2) Situation Complexity	<=3	>=5
(D3) Situation Variability	<=3	>=5
(S1) Vigilance	>=5	<=3
(S2) Attention Concentration	>=5	<=3
(S3) Attention Division	>=5	<=3
(S4) Available Mental Capacity	<=3	>=5
(U1) Amount of Information	>=5	<=3
(U2) Familiarity with the Situation	>=5	<=3

separately, given the complexity of interpreting the user's situation awareness Satuf *et al*. [2016]. To provide a better interpretation of the user experience, we first examined which dimensions had potentially positive or negative results. In the SART instrument, some dimensions, high values (>=5) indicated a positive outcome, while others indicated a negative one; the same was applied to low values (<=3). For example, for the dimension (D3) situation variability (see Table 6), lower values indicate lower demands on the user's attention; consequently, lower values are potentially positive. Thus, Table 7 was elaborated to assist in the interpretation of each SART dimension.

Figure 9 presents the distribution of the sum of the values the participants assigned to each dimension (on a scale of 1 to 7). It also shows the values attributed to each SART component (D, S, and U) to show a comparison of the results of the SART component by notification type.

In Figure 9, we see that, in general, both types of notification had good results when used separately. The results of the figure demonstrate that the haptic notification has a positive highlight (values <=3) in the dimensions of the complexity of the situation (D2-H) and the available mental capacity (S4-H). It is also positive in the dimensions of (S1-H) vigilance, (S2-H) concentration of attention, (U1-H) amount of information, and (H2-H) familiarity with the information, all with higher totals for values >=5. The results also revealed that visual notification, although it requires more attention from the participant since they need to look away to interpret, did not require significant effort (see Figure 9). The dimensions of the amount of information (U1-V) and the familiarity with the situation (U2-V) demonstrate this result.

The results also showed that the redundant use of both types of notifications, that is, together haptic and visual, did not negatively affect the results, except in the dimension of attention division (S3-H + V) which revelead more distributions of the values (see Figure 9). This result presents evidence that the interpretation of two simultaneous alerts overloaded some participants' attention. However, simultaneous use of notifications indicated a low demand for mental capacity (S4-H + V), leading to the conclusion that although it required more attention (S3), the types of notifications were easy to interpret (S4).

7.4 Threats to Validity

The discussion of threats to the validity of the study followed the recommendations of Wohlin *et al*. [2012]. To address internal validity, the order of presentation for haptic and visual notifications was shuffled, and the redundant use of both was tested last. This approach prevented one form of recognition from influencing the other. The external validity was addressed by the representativeness of the participants, being of various profiles. The validity of the construct was strengthened by balancing the participants according to their profiles. The use of different data collection forms helped mitigate threats to the conclusion.

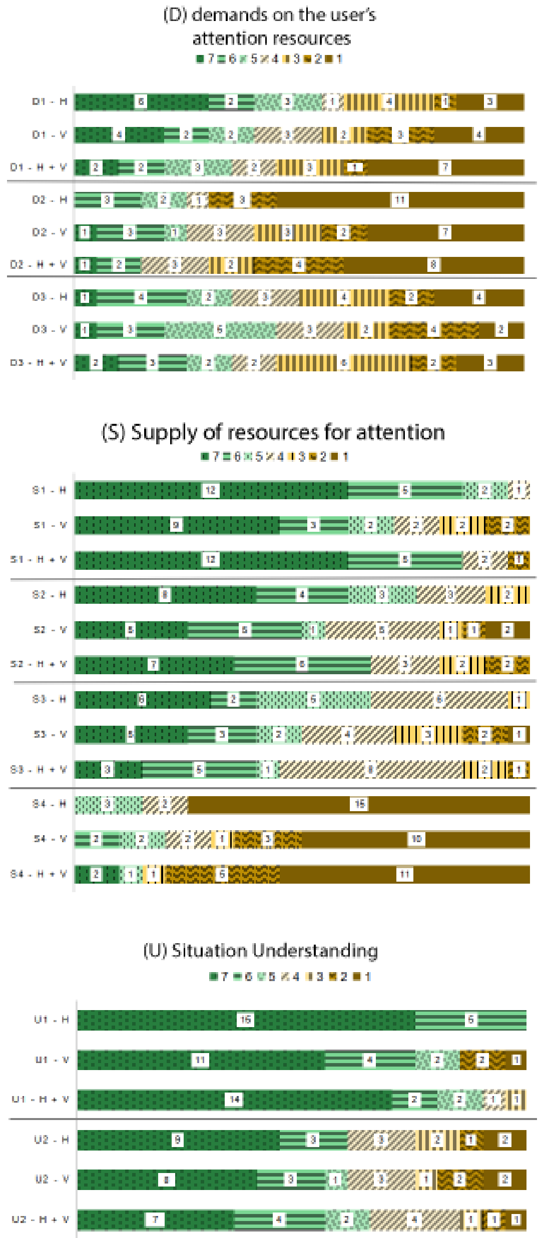


Figure 9. Total for each dimension for each type of notification and separated by SART components.

8 Discussion

Our study was conducted addressing the three RQ presented in Section 3.1. In Section 8.1, we answer the RQs and discuss the main results of the study in relation to the related work. In Section 8.2, we discuss the limitations of our study.

8.1 Study findings

Considering the RQ1 (*What are the relevant characteristics of the driver in the study domain?*), a qualitative study

Table 8. Feedback from participants according to the SART dimensions - (*) type of notification the participant interacted first

SART dimensions	P1*	P2	P3*	P4*	P5*	P6	P7	P8*	P9	P10*	P11	P12*	P13	P14*	P15*	P16	P17	P18*	P19	P20
Haptic																				
(D1)	7	6	7	7	3	1	7	3	4	2	1	3	7	7	5	1	6	5	5	3
(D2)	1	1	1	1	1	1	5	2	4	1	1	1	6	6	2	1	2	1	6	5
(D3)	3	1	4	7	4	1	6	3	3	2	1	2	6	6	5	1	3	4	6	5
(S1)	7	7	7	7	6	7	6	6	4	7	7	7	7	7	5	7	7	5	6	6
(S2)	7	7	6	5	6	7	6	5	4	4	7	7	7	7	4	7	3	5	6	3
(S3)	7	4	7	4	5	5	5	4	4	4	7	7	7	7	6	5	4	6	5	3
(S4)	1	1	1	1	4	1	1	4	1	1	1	1	1	1	5	1	1	1	5	5
(U1)	7	7	7	7	6	7	7	6	7	7	7	7	7	7	7	7	7	6	6	6
(U2)	1	7	3	7	7	4	7	6	4	6	7	7	7	7	6	1	4	7	3	2
Visual																				
(D1)	4	7	1	7	6	1	7	2	1	3	2	1	5	7	2	5	6	4	4	3
(D2)	4	1	1	1	6	1	6	1	4	3	2	3	5	7	2	1	6	1	3	4
(D3)	4	5	4	2	2	1	7	2	5	2	3	5	5	6	6	1	6	4	5	3
(S1)	4	7	7	3	3	2	7	4	7	7	5	7	7	7	6	6	7	2	5	6
(S2)	1	7	7	4	7	6	5	4	4	4	6	6	7	7	4	1	6	2	6	3
(S3)	4	7	6	3	7	7	5	3	4	4	4	5	7	7	2	1	6	2	6	3
(S4)	4	1	1	6	6	5	1	1	2	2	1	4	1	2	1	1	1	1	3	5
(U1)	5	7	6	7	6	7	7	6	7	2	6	7	7	7	7	1	7	7	2	5
(U2)	1	7	4	7	7	3	7	6	4	5	7	6	7	7	6	1	4	7	2	2
Both																				
(D1)	1	4	1	7	5	1	3	1	2	3	1	1	6	7	1	5	6	3	5	4
(D2)	2	1	1	3	4	1	2	2	4	4	1	1	6	7	2	1	1	1	6	3
(D3)	2	5	4	7	3	1	3	3	4	3	1	3	6	7	5	1	6	2	6	3
(S1)	7	7	7	6	7	6	7	4	4	7	7	7	7	7	6	7	7	6	2	6
(S2)	7	7	7	3	7	6	6	4	4	6	4	6	7	7	6	7	6	2	2	3
(S3)	6	4	7	4	6	5	4	4	4	6	4	4	7	7	6	6	4	2	3	3
(S4)	2	1	2	7	2	1	1	7	2	2	1	1	1	1	1	1	1	1	3	5
(U1)	6	7	7	7	7	7	7	7	5	3	6	7	7	7	7	7	7	7	4	5
(U2)	1	7	4	7	7	3	6	6	4	5	7	6	7	7	6	4	4	7	5	2

was carried out by conducting interviews with 11 individuals who were typical drivers in the study context (see Section 4). Through qualitative analysis using the coding technique, we identified two personas that characterize drivers who exhibit cautious and attentive behaviors, and another that represents those with a more aggressive driving style.

As described in Lindgren *et al*. [2007], our research developed personas using demographic and behavioral information from users by adopting a qualitative approach, specifically semi-structured interviews, to enhance the creation of these personas. Nevertheless, our personas diverge from those proposed by Lindgren *et al*. [2007] as they provide additional details regarding the ADAS notification type and driver behavior. Similarly to our approach, Brinkley [2021] used personas in collaborative workshops to offer valuable information for the development of ADAS. However, their personas focused mainly on visual impairments, while in our case, it was only a characteristic of our audience.

To answer the RQ2 (*What are the types of notifications that best meet the demands of the domain?*), a co-design workshop was carried out with a total of 9 participants, comprising common users (ie, typical drivers on busy roads) and technical users (ie, individuals with experience in vehicle systems), who were divided into three groups (see Section 5). As result, four low-fidelity prototypes were developed, i.e., three by each group individually and one by all participants collaboratively. These prototypes featured various types of alert notifications strategically placed in different areas of the vehicle.

Considering the low-fidelity prototypes produced in the workshop, it is observed that the 3 groups proposed the use of different types of notification, including sound, visual, and haptic (see Figure 5). They also suggested that notifications should be used in redundancy, which is a similar adoption presented in [Frison *et al*., 2019b] work. By examining the prototypes (see Figure 5) and analyzing the consolidated findings (see Table 5), we could confirm that all the prototypes recommended the use of alert notifications on the steering wheel. Even without having any type of prior recommendation on good practices in ADAS design, the participants' solutions focused on presenting information on the alert situation in simple and easy-to-interpret formats, as suggested by Li *et al*. [2020]. Similarly to Sun *et al*. [2021], we carried out a co-design workshop to create an ADAS system, although with a different objective. Like the Sun *et al*. [2021] work, our co-design workshop was conducted considering prior knowledge about end users. In the case of this paper, previously created personas were considered.

Finally, the RQ3 (*Which type of notification requires less interpretation effort?*) was answered by performing an evaluation study. The four low-fidelity prototypes proposed in the co-design workshop were analyzed and a single consolidated prototype was proposed. A high-fidelity functional prototype with two types of notification was implemented, i.e., visual and haptic, considering the technical feasibility of implementing the notifications based on the consolidated prototype; both notification systems were installed in a test vehicle (see Section 6). A total of 20 drivers participated in the evaluation of the notification system (see Section 7). The results revealed a good acceptance of both types of notifications, with an emphasis on haptic notifications, which required less effort to interpret, as measured by SART.

The evaluation results revealed that visual notification was well accepted, as presented in the work of Li *et al*. [2020]. This result may be a consequence of this type of notification being the most common in ADAS [Naujoks *et al*., 2019]. However, haptic notification presented high rates in the components of situation understanding (U), the supply of attention resources (S), and the demands on the attention resources of the user (D) (see Figure 9. The demand for security information that varies according to the context was handled by the system proposed in this article. In the visual notification format, the variations were conveyed through different colors and icons that illustrate the criticality of the context. In the haptic format, the variations were indicated by the intensity of the signal vibration. Criticality is also addressed and highlighted by Frison *et al*. [2019a] as a critical factor so that the driver can understand the demands of their actions to maintain driving safety, especially in vehicles with low notification automation.

8.2 Limitation of the work

We understand that our sample sizes in the different phases of our investigation have representativeness by covering potential users of the notification system. However, we have the conscious that we could not cover a great amount of users in the different steps. The purpose of developing personas in our study was to provide the participants of the co-design workshop with a user-centered background. To create more comprehensive personas that demonstrate characteristics of various Brazilian cities, it is suggested that a survey be conducted in terms of participant coverage and collection time.

In terms of notification types, we can point out the non-implementation of the sound notification represents a limitation. This notification type was proposed in the co-design workshop; however, our partner imposed limitation with regards of the manipulation of the vehicle's sound system. The integration of the notification system into a specific vehicle model can be seen as a limitation, as different vehicles have varying technologies associated with their ADAS systems. However, the proposed notifications can be easily developed for others vehicle models or brands using technologies proprietary to those vehicles.

ADAS evaluation has some limitations, particularly related to safety. Evaluations with end-users are often carried out through simulations of traffic conditions using augmented reality and mixed reality with small samples of users [Sun *et al*., 2021]. Although simulation spaces for the automotive sector provide a safer environment for users, laboratories with the necessary configuration are expensive and not easily found. As we did not have access to a simulation laboratory, we opted to conduct the evaluation in a real environment, where the notifications could be tried out and evaluated by users. However, we are aware of the need for tests with more variability of scenarios.

9 Conclusion

This paper proposed a system to alert drivers about dangerous situations when motorcycles are identified in the vehicle blind spot. The proposed system notifies the driver using a visual and haptic format, informing the criticality of the situation through notifications. The result was achieved through a series of steps, starting with the identification of the user needs through interviews and qualitative analyzes, which resulted in the creation of *personas*. These personas served as a reference for the creation of prototypes generated by the end-users during a co-design workshop. After consolidating the workshop proposals, a functional prototype was developed and evaluated by end-users in an internal circuit at the Centro Universitário Facens. This assessment considered the cognitive effort of users to interpret information from different types of notifications.

The personas created from the interview data represented two groups of users with different driving styles, one cautious and the other more aggressive. Furthermore, both personas had a certain degree of vision issues. The low-fidelity prototypes produced in the co-design workshop demonstrated that users were concerned about generating alerts using different types of notifications. However, after considering the technical feasibility, the functional alert system incorporated two types of notification, visual and haptic. The evaluation of the system, using notifications in visual or haptic formats and both in redundancy, demonstrated good acceptance by users. However, it was observed that the haptic format obtained positive results in most of the cognitive effort dimensions evaluated.

Our findings indicate that haptic notifications were preferred because it required less cognitive effort to interpret them. This result added a new significant outcome for the design of ADAS notifications, as previous literature had indicated a preference for visual warnings. Although the combined use of both notification types (i.e., visual and haptic) showed positive results, we recognize that additional studies are needed to explore other combinations of notification modality. Further research should also investigate the use of different alerts in varying contexts to determine whether there is a relationship between the preferred type of notification and driving conditions (e.g. rain, snow, heavy traffic).

The qualitative data collected through the *think-aloud* method during the system evaluation was not explored and compared with the quantitative results. It is also future work to implement other notification solutions proposed during the co-design workshop. Finally, we intend to conduct new rounds of evaluations with the notification types in the auto-simulation lab, a new augmentend reality laboratory created at Facens.

Declarations

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Authors' Contributions

Felipe Pires: Conceptualization, software development, data curation, investigation, formal analysis, and writing – original draft.

Pedro Lisboa: Conceptualization, software development, data curation, investigation, and writing – original draft. Herick Ribeiro: Project administration, supervision, validation, and writing– review editing. Pietro Campos: Project administration, funding acquisition, and writing – review editing. Marc Capdevila: Writing – review editing. Luciana Zaina: Conceptualization, methodology, project administration, investigation, supervision, validation, and writing – original draft.

Competing interests

The authors declare that they do not have competing interests.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available in the paper.

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