

# UX Design and Evaluation of Warning Alerts for Semi-autonomous Cars with Elderly Drivers

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**Abstract:** This paper presents a study on user experience (UX) design and evaluation of warning systems intended for older adults in semi-autonomous cars. We used combinations of visual, auditory, and speech modalities to design the warning alerts and created three low-fidelity, video-based prototypes. We conducted user tests with elderly drivers, both in the lab and remotely, within a test-and-refine approach involving three experiments. The methods used for data collection included Wizard of Oz, standard questionnaires and interviews. We collected qualitative user feedback and self-reported ratings of user experience and cognitive load. We report on the iterative development of our design solution, findings from these user studies, and our methodological insights, that UX researchers and practitioners could use in similar settings.

## 1 INTRODUCTION

As the automotive industry is making progress towards driving automation, drivers are embracing many technological advancements. Several publications discuss how to enhance the driver-car interaction and help drivers adapt to the different levels of autonomous driving (Strömberg et al., 2019; Debernard et al., 2016). However, elderly drivers have often been left out of scope (Young et al., 2017) although they represent a growing market for the automotive industry. In 2017, people above 65 accounted for almost one-fifth of the European population (Eurostat, 2017), and by 2050, they might account for one-sixth of the total population (United Nations, 2019). One of the few studies focused on elderly drivers (Schmargendorf et al., 2018) shows that despite concerns about security issues, system failures or hacking attacks, elderly drivers have a large interest for Autonomous Vehicles (AVs). Specifically, the benefits associated with AVs include increased safety, shorter traveling times, and more comfortable driving. Furthermore, according to Rödel et al. (2014), seniors are much more favorable toward future autonomous cars compared to younger drivers. Therefore, it is vital to ensure that the design of automotive Human Machine Interfaces

(HMI) caters to their specific needs and gives them a sufficient amount of trust to adopt the technology.

During the quest toward automation, the automotive industry has developed various Advanced Driver Assistance Systems (ADAS) that are already available in modern cars to bring more safety, comfort and pleasure while driving (Insurance Institute for Highway Safety (IIHS), 2020). Amongst them, Lane Keeping Assistant (LKA) and Adaptive Cruise Control (ACC) allow the driver to supervise the driving rather than directly controlling the car. This enables the first level of autonomy according to the Society of Automotive Engineering (SAE). Next are levels 2 and 3 that let the car perform takeovers and make complex decisions, but require the driver to always be aware of the road situation and be ready to drive when requested. If the vehicle fails to cope with the road situation, the takeover request will be issued and the driver will need to take back the control (SAE, 2018). Zhou et al. (2019) identified four topics pertinent to the takeover situations in autonomous driving: (1) drivers being aware of whether the vehicle can continue operating safely in given conditions; (2) the system's capability of warning drivers for any dangers or conditions requiring the driver to take over; (3) automation capability awareness; (4) warning effectiveness.

This paper focuses on topics 3 and 4 and reports how we designed and tested warning alert systems in semi-AVs with the goal of ensuring that elderly

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drivers of level 2 or level 3 cars are well informed of the danger while driving. To achieve this goal, we created and tested low-fidelity video-based prototypes and explored different combinations of modalities to notify the driver of the surrounding events: visual, non-verbal auditory and voice outputs. We adopted an iterative test-and-refine approach, which allowed us to rapidly set up user tests and improve the prototypes between iterations. During three successive experiments, we collected and analyzed data about the user experience (UX), the cognitive load and the participants' subjective responses to the proposed prototypes.

## 2 RELATED WORK

The contribution from the human-computer interaction (HCI) community to AVs for elderly drivers focuses on safety features but remains insufficient (Rhiu et al., 2015). We try to fill this gap building on prior studies applied to danger awareness. Specifically, we selected the most common modalities used to inform senior drivers reported in the literature: voice messages, beep sounds, and visual messages. Senior drivers have difficulties detecting tactile stimuli and they pay more attention to the road than younger drivers when they are engaged in secondary tasks even when the car is driving in semi-autonomous mode (Huang and Pitts, 2020). Additionally, we used the words "Danger", "Warning" and "Notice" to convey urgency as a function of the distance from the critical road situation, as Baldwin and Lewis (2014) reported that the perceived urgency of the word "Danger" was higher than the words "Warning" and "Notice". Finally, using more annoying sounds results in faster reaction times in handover and takeover situations (Kutcheck and Jeon, 2019). These studies also recommend keeping the duration of the sounds short, not to delay the driver's reaction.

Most studies use advanced driving simulators to perform experiments and rely on quantitative data collected from a larger sample of participants (Gerber et al., 2019; Koo et al., 2015; Kutcheck and Jeon, 2019; Politis et al., 2015). In this work, we used a video-based driving simulation that allowed us to conduct tests remotely during the coronavirus outbreak. Video prototypes were previously used to examine drivers' memory for auditory alerts (Nees et al., 2016), to check whether owner's manuals can help drivers better understand car's automation capabilities (Boelhauer et al., 2019), as a design technique for human-vehicle interactions (Pettersson and Ju, 2017), and the HMI design for highly automated driving (Richard-

son et al., 2018). In addition, we decided to focus on a thorough qualitative analysis collected on a smaller sample of users. We made this choice in hope of having a better understanding of underlying user needs that will be used in the future development of prototypes and allow for the collection of behavioral data.

## 3 METHODOLOGY

We performed three experiments (designated in the following XP1, XP2, XP3) within a formative UX design approach in order to (1) investigate elderly drivers' subjective responses about the proposed danger alert system and (2) explore the application of voice interaction in the context of warning effectiveness in semi-autonomous cars. The formative approach allowed us not only to receive early feedback to be incorporated into the prototype of the future system, but also to identify the target users' needs. Furthermore, we relied on cost-efficient prototyping methods, namely video prototyping and Wizard of Oz (WOz) to quickly iterate on our design solutions in an industrial setting.

In addition, we wanted to identify which of the following seven types of alerts would provide users with the best possible warning: (C1) speech only (VB), (C2) sound only (S), (C3) visual-only (V), (C4) speech + sound (VB + S), (C5) speech + visual (VB + V), (C6) visual + sound (V + S), and (C7) speech + sound + visual (VB + S + V). We used C1; C3-C7 in XP1 and XP2, and C1-C6 in XP3. We eliminated C2 from XP 1 and XP2 because we assumed that the sole use of beeping sounds with no additional information regarding the upcoming danger would not be useful to drivers. We reintroduced it in XP3 because we assumed this might trigger the interaction between the car and the driver. We removed C7 from XP3 as this condition was judged too complex by the participants from XP1 and XP2.

### 3.1 Data Collection Methods

We used questionnaires and interviews as data collection methods. We used the user experience questionnaire (UEQ), a standard instrument for evaluating UX constructed and validated by Laugwitz et al. (2008), which measures the perceived UX across six scales: Attractiveness (AT), Perspicuity (PS), Dependability (DP), Efficiency (EF), Novelty (NV), and Stimulation (ST). PS, DP, and EF measure the pragmatic attributes of UX, ST and NV the hedonic attributes of UX. Attractiveness is considered separately. UEQ helps to determine the areas of improvement, indicating what

experiential qualities need improvement to impact UX the most (Schrepp et al., 2014). NASA-Task Load Index (NASA-TLX) is a post-task six-dimensional scale designed to assess the subjective workload of the participants while performing a task. It is widely used due to its easy administration and a relatively wide range of application domains such as aviation, military, automobile drivers, and healthcare (Hart, 2006). Most studies report its use in relation to interface design and evaluation. NASA-TLX consists of two parts. In the first part, the participants need to identify the sources of workload to obtain the weights for each of the six scales. In the second part, participants rate the workload of the task on each of the six subscales. In XP3 we added a Single Ease Questionnaire (SEQ) to measure the ease of use of the warning system.

We modeled the first two experiments similarly to Frison et al. (2019), in which the authors used the laddering technique defined by Reynolds and Gutman (1988) to probe the participants to discover the underlying psychological needs while driving an automated vehicle. We used the laddering technique to ask questions about participants' understanding of warnings, their opinion about them, and the further clarification of ratings in the standard questionnaires administered to them. The quantitative data collected through UEQ, SEQ and TLX helped us explain the qualitative findings gained from the interviews in more detail and explore the thoughts and attitudes of participants as a part of the iterative UX design process.

### 3.2 Participants

We recruited senior drivers, older than 50, through a recruiting agency. They were all active drivers, with more than 20 years of driving experience, interested in AVs, and reported frequent use of ADAS (LKA, AAC) and GPS systems. Six participants (1 female) aged between 64 and 75 ( $M=68.5$ ,  $SD=3.819$ ) participated in XP1. They were all in good health and did not have any type of physical disabilities. Six conditions (C1, C3-C7) were presented to each participant, resulting in 36 trials overall.

Six participants (2 females) aged between 52 and 75 ( $M=66.5$ ,  $SD=7.251$ ) participated in XP2. Five had participated to XP1, one had not. We recruited the same participants for two reasons. First, we work in a formative approach where we frequently design and evaluate system prototypes with a small sample of users. Second, for organizational purposes, we did not have to go through the recruitment process again, which included finding new participants and conducting interviews with them.

Six participants (2 females) aged between 55 and

69 ( $M=61.17$ ,  $SD=5.269$ ) participated in XP3. They were all different from the participants in experiments 1 and 2. We divided the participants into two groups. One group only saw the conditions containing visual warnings (C3,C5,C6), while the second group only saw the conditions without visual warnings (C1,C2,C4), resulting in 18 trials overall.

### 3.3 Procedure

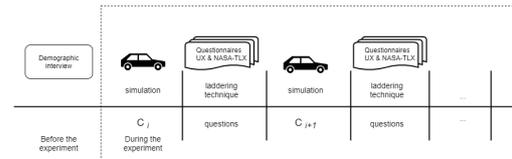


Figure 1: The experimental procedure.

Fig. 1 shows the experimental procedure. First, the researcher explained to participants the study procedure without revealing the underlying research questions. After signing a consent form, participants answered a few demographic questions and filled out a questionnaire regarding their attitude towards AVs Boelhouwer et al. (2019). XP1 took place in a lab room where the participants sat in front of a big-screen TV, next to which a smaller screen-sized laptop was placed, simulating the car's infotainment screen and displaying the visual warning messages. Speech messages and beep sounds were played through a set of stereo speakers placed behind the TV. In experiments 2 and 3, we used a remote testing method, where the participants and the researcher were on different physical locations, the researcher moderating the session using an online tool for remote user research. We videotaped each session.

We instructed participants to imagine they were driving an AV with a limited ability to deal with on-road situations and the situation might request a takeover. However, no driver response was ever required. Thus, their task was to pay attention to and understand the road situation and warning alerts, similar to what they would have done in an SAE level 3 car. The experiment began after explaining the scenario to the participants. After each condition, the researcher would ask questions such as "What happened in the video?", "What do you think about the warning alerts?", "What were you focused on during the drive?" or similar follow-up questions to better understand the participant's reasoning. Afterward, the researcher administered the NASA-TLX. In XP3, the SEQ rating sheet preceded the NASA-TLX. At the end of the session, participants completed the UEQ.

Table 1: Design of warnings for experiment 1.

Condition	Low Urgency (LU)	Medium Urgency (MU)	High Urgency (HU)
C1 (VB)	Voice message: "Hey, there is a slow truck on the road in 100 m. Pay attention!"	Voice messages: "Be vigilant, a slow truck in the right lane in 50 m."; "Warning! You are approaching an obstacle!"	Voice message: "Slow down and change the lane as soon as possible."
C3 (V)	Warning, slow truck 100 m ahead of you! 	Warning, slow truck 50 m ahead of you! 	Change lane as soon as possible 
		Warning, you are reaching the obstacle 	
C4 (VB+S)	Voice message as in C1 + beep sound	Voice message as in C1 + beep sound	Voice message as in C1 + beep sound
C5 (VB+V)	Voice message as in C1 + visual warnings as in C3	Voice message as in C1 + visual warnings as in C3	Voice message as in C1 + visual warnings as in C3
C6 (V+S)	Visual warnings as in C3 + beep sound	Visual warnings as in C3 + beep sound	Visual warnings as in C3 + beep sound
C7 (VB+V+S)	Voice message as in C1 + Visual warnings as in C3 + beep sound	Voice message as in C1 + Visual warnings as in C3 + beep sound	Voice message as in C1 + Visual warnings as in C3 + beep sound

## 4 EXPERIMENT 1

In all conditions, we used the same video prototype simulating a car equipped with ADAS functions such as LKA, AAC and autonomous overtake. Such simulation corresponds to SAE level 3 of automation. The driving scenario consisted of highway driving, where the car warned the driver about an obstacle ahead, overtook a long truck in the right lane by going to the left lane and subsequently returned to the right lane. The video lasted 80 seconds. We reused a part of the video from the public dataset made available by the DR(eye)VE project (Palazzi et al., 2018).

### 4.1 Warnings

The warnings (Table 1) involved three levels of urgency similarly to Politis et al. (2015): low-urgency (LU) at the beginning of the scenario, medium-urgency (MU) before reaching the obstacle and high-urgency (HU) immediately before reaching the obstacle. The video followed a low-medium-high sequence of urgency. The level of urgency is defined as a function of the distance between the car and the obstacle or a dangerous event. The warnings were not repeated.

We wrote the voice alert messages which were then produced using a Text-To-Speech (TTS) system. We used a warm-toned male voice, speaking with a standard British accent, conveying authority but also empathy. We worked with developers to write the content of the messages using informal language. As the prototype also involved sound alerts, we downloaded a beep sound from <http://freesound.org> available under Creative Commons license, free for anyone to use, modify, and distribute. The visual warnings consisted of textual messages along with the commonly used red triangle, which is known to be the most recognized sign by drivers (Luoma and Rämä, 2001). Sometimes, a descriptive image of the upcoming car operation was added, such as lane change. In our warning design approach, we thought about the driver’s awareness of the situation. Therefore, the sequence of warnings should prepare the driver well enough and in advance for the upcoming danger. Thus, HU warning messages already assume the driver is aware of the situation, and only give them a last alert or notice about the following action. In fact, that is why the triangle is omitted in HU.

## 4.2 Quantitative Results

Figure 2 shows the mean UEQ scores per dimension. The prototype scored lowest on the pragmatic qualities, namely, DP (1.08), and EF (1.88). These low scores can be attributed to a lack of direct interaction with the prototype. The prototype scored higher on AT (2.08), PS (2.17), ST (2.17) and NV (1.92). According to the UEQ benchmark, values above +2 are considered very positive, and below -2 as very negative. Although the values we obtained are high, except for DP, our sample is probably too small to achieve high precision with respect to the benchmark. A high PS score tells us that the warnings are easy to get familiar with, while AT signifies that participants' impression of the system was positive.

## 4.3 Qualitative Results

We performed an exploratory thematic analysis of the data collected during interviews (Table 2). Generally, participants reported that the voice messages were too friendly and too long, referring to other systems using polite words such as *please* or having a friendly tone, which they do not appreciate. Timely and coherent warning about the upcoming danger should suffice. This finding is in line with previous research on autonomous car's voice alerts where a higher level of assertiveness results in faster reaction times and conveys a higher level of perceived urgency (Wong et al., 2019). Thus, we decided to shorten the voice alerts and make them more assertive.

Participants often mentioned that visual warnings are distracting and contain too much text. When using voice and visual warnings together, the text in visual warnings should correspond to the content of the voice messages. That reduces the workload while comparing what is being said and what is being shown on the screen. The beep sound is considered useful for preparatory purposes and drawing the driver's attention before hearing or seeing the actual warning. But, the beep should be followed by the warning without a delay. Additionally, the beep sound was not very pleasant. The participants consistently reported that the warnings should give precise information about the upcoming event. In our case with a slow-moving truck, the warning mentioning an obstacle ahead makes the drivers think about static objects on the road that impede the traffic flow, which increases confusion and stress. Finally, there should be a difference between warning messages and simple informative messages.

## 5 EXPERIMENT 2

XP2 aimed to fix some issues in the design of warnings, confirm the findings from XP1 and collect participants' feedback once again. We built a new prototype based on a video that we recorded ourselves. Using a front-mounted camera in the car, we recorded several situations while driving on the highway. We selected the situation displaying the roadworks in the left-most lane of a three-lane highway. Lane change was required. The video lasted 80 seconds. We used the same six conditions (C1, C3-C7), resulting in 36 trials overall. We added the TLX: after the first condition, participants identified the sources of workload; after each condition, participants filled out a TLX rating sheet. Finally, we used remote testing setting with videoconferencing instead of a lab setting.

### 5.1 Improved Warnings

We synchronized visual warnings with other modalities and moved them from a separate screen to the video screen, thus simulating a Head-Up Display (HUD). We assumed this would make it more efficient for the drivers to see the visual warnings, compared to when they are displayed aside (e.g. on a car's infotainment screen). We also reduced the amount of text included in visual warnings. In addition, we selected another beep sound, which had a duration of 2.797 seconds. Finally, we rewrote the voice alerts to be more informative and direct, but less friendly. We used the same voice as in XP1 (Table 3).

### 5.2 Quantitative Results

Compared to XP1, AT, PS, and DP scores increased to 2.194, 2.208, and 1.50, respectively. EF, ST, and NV decreased to 1.75, 1.54, and 1.58, respectively (Figure 2). A t-test revealed no significant differences between mean scores for all scales between XP1 and XP2 ( $\alpha < .10$ ). The DP score is the lowest in both experiments, 1.083 and 1.50 respectively. The EF score is second lowest in both experiments. This could be attributed to the properties of the experimental design. The participants were only watching the video and observing the situation, thus scoring low on feeling in control and ease of use. Therefore, the results reflect the lack of control and interaction between the car and the driver, as well as imply that participants need to make a lot of effort to understand the warnings.

We calculated the means of the unweighted TLX scores for each subscale and the overall TLX score (Table 6). Mental demand and temporal demand were the dominant sources of workload in XP2. Condi-

Table 2: Thematic analysis of the participants feedback in experiment 1.

Theme	Code	Frequency	Condition	Participant
Attention	Beep draws attention	5	C3, C7	P4, P5, P6
Attention	Visuals can easily be missed	3	C3, C6	P2, P3, P4
Attention	Delay between the beep and visual warnings	2	C6	P5
Attention	Visual warnings are distracting	2	C3	P4, P6
Attention	Simple to follow with voice and visuals	1	C5	P3
Attention	Voice warnings allow me to focus on the road	1	C1	P4
Attractiveness	Voice is too friendly	3	C1, C5	P2, P5
Attractiveness	Voice would interrupt music	1	C6	P2
Content	Truck is not an obstacle	3	C1, C7	P2
Cognitive Load	Too much information	4	C4, C7	P2, P3, P5
Cognitive Load	Voice messages are too long	3	C1, C4, C7	P6
Cognitive Load	System talks too much	2	C1, C4	P2
Cognitive Load	Visuals and voice are too demanding	2	C5	P4, P5
Cognitive Load	Concurrent reading and listening is difficult	2	C5,C6	P2
Cognitive Load	Listening is easier than reading	1	C5	P2
Preference	Beep and voice is preferred	2	C6, C7	P6
Preference	Voice warnings not necessary	1	C7	P3
Preference	Voice warnings are preferred	1	C3	P4
Preference	Visual warnings and beep are preferred	2	C1,C3,C5	P3,P4
Stress	Beep is annoying	4	C1, C4, C6	P2, P4
Stress	Voice warnings become annoying on long-term	2	C4, C6	P3
Stress	Beep is stressing	1	C4	P4
Usefulness	Voice warnings are useful	2	C1, C5	P4
Usefulness	Visual warnings are not useful	3	C3	P6
Usefulness	Beep sound is confusing	1	C6	P3

tions containing visual warnings have a higher mean TLX score (34.6), compared to the conditions without visual warnings (29.1). Unimodal combinations (C1,C3) and multimodal combinations (C4-C7) have a mean score of 31.3 and 33.5, respectively.

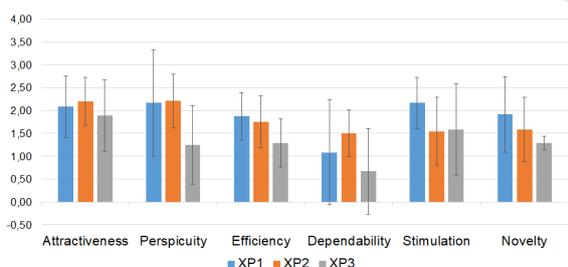


Figure 2: Mean UEQ scores between XP1, XP2 and XP3.

### 5.3 Qualitative Findings

Table 4 summarizes the thematic analysis of the participants’ subjective feedback. Most participants found the beep warning useful and pleasant and agreed that it drew their attention and worked well in combination with other modalities. Similarly, participants agreed that voice warnings were useful and concise, although sometimes lacking dynamics or be-

ing bothersome. In fact, there is a concern that voice warnings might be intrusive, disturbing for some drivers, which could lead to a loss of interest for them. One participant expressed concerns related to the integration of voice warnings with other voice-based systems already present in the car.

Most participants found visual warnings distracting, which is also reflected in TLX scores when visual warnings are present. Some stated that listening is easier and some that visual warnings are easy to miss while driving. Even after we decreased the amount of text, the visuals still required a high level of attention. Participants stated that visual warnings could serve well as a backup in situations where they would miss the voice warning, to check it manually. This finding is in line with previous research reporting that text-only warnings are the longest to process and are the least preferred by participants (Cao et al., 2009). Two participants expressed the need for a repeat option. This additional feature might be useful in the case drivers would miss the alert, e.g., while listening to the radio or talking to other passengers in the car.

Table 3: Design of warnings for experiment 2.

Condition	Low Urgency (LU)	Medium Urgency (MU)	High Urgency (HU)
C1 (VB)	Voice message: "Notice! There are roadworks in the left lane in 200m. Pay attention!"	Voice messages: "Warning! I am going to the middle lane now."; "Notice! Pay attention to the truck in the right lane."	Voice message: "Warning! You are approaching the roadworks in the left-most lane. Be careful!"
C3 (V)	 	 	
C4 (VB+S)	Voice message as in C1 + beep sound	Voice message as in C1 + beep sound	Voice message as in C1 + beep sound
C5 (VB+V)	Voice message as in C1 + visual warnings as in C3	Voice message as in C1 + visual warnings as in C3	Voice message as in C1 + visual warnings as in C3
C6 (V+S)	Visual warnings as in C3 + beep sound	Visual warnings as in C3 + beep sound	Visual warnings as in C3 + beep sound
C7 (VB+V+S)	Voice message as in C1 + visual warnings as in C3 + beep sound	Voice message as in C1 + visual warnings as in C3 + beep sound	Voice message as in C1 + visual warnings as in C3 + beep sound

## 6 EXPERIMENT 3

XP3 aimed to investigate if and how drivers interact with warning alerts assuming they are driving an SAE level 3 car. The driving context consisted of city driving with medium traffic density. The conditions C1-C6 were shown to the participants. In a between-subjects design, half of the participants were exposed to conditions without visual warnings (C1,C2,C4), and half to the conditions with visual warnings (C3,C5,C6). We also administered the SEQ after each condition to evaluate the users' task difficulty on a 7-point scale. We simulated the vocal system of the car with a WOz, a prototyping method involving a human operator (wizard) to simulate one or more parts of the system while the user is interacting with it. WOz is relevant in the early design stages of systems involving speech and gestures, as it allows the exploration of different design alternatives. WOz is often used to study the design of automotive user interfaces (Pettersson and Ju, 2017), commuter experience in autonomous cars (Krome et al., 2017), and for real-time observation and interaction prototyping in vehicles (Martelaro and Ju, 2017). We developed a simple web application coupled to a TTS module to simulate the voicebot. The first author moderated the

session, while the second was in the role of a wizard, invisible to the participants.

### 6.1 Interaction Design

We instructed participants that their task was to monitor the road and follow the warning alerts. The wizard supported the following tasks: alerting the driver about the obstacles ahead, repeating the warning, explaining the warning to the driver, and explaining why is the car making certain manoeuvres. They had to start each new interaction sequence with the keyword "Tony", which was the name of the voice assistant. We told participants to use natural language when interacting and to try to stay within the limits of the supported tasks. However, the wizard still tried to address participants' requests that were out of scope whenever possible. This led us to even more discoveries. To better understand whether drivers would interact with their car about the warnings, we counted the number of times participants triggered interaction ("pull requests"). We hypothesized that there would be more pull requests when participants are exposed to unimodal conditions, such as C1 and C3. The video lasted 5 minutes.

Table 4: Thematic analysis of the participants’ feedback for experiment 2.

Theme	Code	Frequency	Condition	Participant
Adaptation	Attention to voice alerts could fade over time	1	C1	P4
Attractiveness	Beep is pleasant	3	C4,C6	P2,P4,P5
Attractiveness	Voice messages are too long	2	C1,C4	P5
Attractiveness	Voice messages are concise and friendly	1	C4	P4
Attractiveness	The voice messages lack dynamics	1	C1	P6
Attractiveness	Voice is friendly	1	C7	P6
Attention	Beep draws attention	6	C1,C3-C6	P1,P3,P4,P6
Attention	Reading is distracting	2	C3	P1
Attention	Voice messages are disturbing	2	C1,C7	P4
Attention	Repeating the warnings would be distracting	1	C1	P4
Attention	The beep announces an event	1	C6	P4
Attention	Beep signifies importance	1	C4	P1
Completeness	Visual warnings only are not sufficient	3	C3,C6	P6
Completeness	Voice message is enough	1	C1	P2
Customization	Repeat option is needed	4	C1,C4,C6,C7	P1,P6
Customization	On-demand explanation is needed	1	C1	P3
Comfort	Voice messages are tiring	1	C1	P4
Cognitive Load	Visual warnings are distracting	9	C1,C3,C5,C6	P1,P2,P4,P6
Cognitive Load	Listening is easier	5	C1,C3,C5-C7	P1,P2
Cognitive Load	Too much information	3	C7	P2,P5,P6
Cognitive Load	Voice messages are lighter to process	1	C5	P4
Cognitive Load	Voice warnings are too detailed	1	C5	P1
Cognitive Load	Visual messages are concise	1	C6	P5
Integration	Mix of voice and visual warnings is heavy	1	C5	P5
Interruption	Only critical alerts can interrupt the music	2	C3,C4	P3,P6
Interruption	Annoying if voice alert interrupts music	1	C5	P4
Interruption	Beep interruption is better	1	C5	P4
Perception	Position of the visual warnings is not good	3	C3,C5	P2
Perception	Visuals-only are too easy to miss	2	C3	P6
Perception	Voice warnings are easy to miss	1	C4	P4,P6
Preference	Beep and visual message is the best	4	C1,C3,C7	P3,P4,P5
Preference	Beep and voice message is the best	2	C5,C7	P2
Reassurance	Warnings make me feel safe .	3	C3,C4,C7	P3,P6
Reassurance	Visual warnings are a good backup	2	C5	P3, P6
Stress	Warnings make me feel uneasy	1	C7	P6
Stress	Warnings are too close to the road event	1	C7	P3
Stress	Missing the warning is stressful	1	C1	P6
Stress	Voice messages are stressful	1	C5	P6
Stress	Missing the warning is dangerous	1	C6	P6
Usefulness	Sound and visual message when driving	1	C1	P3
Usefulness	Warnings give a lot of helpful information	1	C7	P6
Usefulness	Visual description of lane change is useful	1	C6	P1
Visual Design	Visual warnings are clear	3	C3	P1,P4

## 6.2 Warnings

Assuming that the drivers would interact with the system, we decided to include the condition C2. But we excluded the condition C7 because using three modalities proved to be too complex in the two previous experiments. Furthermore, the new scenario did not include the HU level, but only LU and MU. This de-

cision was made because HU situations would not give enough time to the participant to interact with the car. Conditions C1,C4,C5 contained voice warnings that were always pushed to the driver. LU voice warnings all started with the word "notice", and consisted of traffic jam alerts ("Notice! Queue of cars in 50 meters. Slowing down."), side hazards ("Notice! Stopping to give priority."), and lane change ("Notice!

Table 5: Thematic analysis of the participants' feedback for experiment 3.

Theme	Code	Frequency	Condition	Participant
Responsiveness	System not responsive to commands	5	C1,C4,C5	P1,P4-P6
Responsiveness	System not responding fast enough	4	C1-C3,C6	P1,P2,P4
Driving style	Disapproving with driving style	9	C1-C3,C5	P1-P3,P5
Confusion	Understanding of warnings	3	C1,C2	P3
Preference	Voice notifications are preferred	3	C6	P4,P5
Preference	Beep is needed	2	C4,C6	P4,P5
Adaptability	Reaction to negative feedback is needed	8	C2-C6	P1,P2,P4-P6
Trust	Voice notifications are reassuring	5	C2,C3,C4	P1,P2,P4,P6
Learnability	Voice messages allow to get to know the system	5	C3,C6	P2,P3,P5,P6
Comfort	Voice messages are interrupting	3	C3,C4	P1,P3,P6

Table 6: NASA-TLX Subscale Scores. MD = Mental Demand; PD = Physical Demand; TD = Temporal Demand; P = Performance; E = Effort; F = Frustration; M = Mean; CD = Condition.

CD	MD		PD		TD		P		E		F		M	
	XP2	XP3												
C1	35	52,5	21,7	16,7	35,8	35	30	11,7	23,3	16,7	28,3	20	<b>29</b>	<b>25,4</b>
C2	-	56,7	-	15	-	41,7	-	15	-	48,3	-	38,3	-	<b>35,8</b>
C3	46,7	75	32,5	45	35	87,5	39,2	87,5	25,8	80	22,5	90	<b>33,6</b>	<b>77,5</b>
C4	35	51,7	20,8	15	40,8	50	34,2	26,7	21,7	30	22,5	25	<b>29,2</b>	<b>33,1</b>
C5	44,2	66,7	18,3	33,3	40	56,7	37,5	35	39,2	40	26,7	26,7	<b>34,3</b>	<b>43,1</b>
C6	48,3	65	30,8	33,3	45,8	63,3	22,5	46,7	30,8	60	27,5	43,3	<b>34,3</b>	<b>51,9</b>
C7	58,3	-	29,2	-	50	-	34,2	-	37,5	-	26,7	-	<b>39,3</b>	-
M	<b>44,6</b>	<b>61,3</b>	<b>25,6</b>	<b>26,4</b>	<b>41,2</b>	<b>55,7</b>	<b>32,9</b>	<b>37,1</b>	<b>29,7</b>	<b>45,8</b>	<b>25,7</b>	<b>40,6</b>	<b>33,3</b>	<b>44,5</b>

Slowing down to change the lane.”). MU voice warnings started with the word ”warning” and consisted of pedestrian alerts (”Warning! Pedestrian crossing the road!”), collision avoidance (”Warning! Slowing down to avoid collision.”), and side hazards (”Warning! Car on the right!”). We used green (LU) and orange (MU) bounding boxes (Fig. 3) to highlight the obstacle visually.

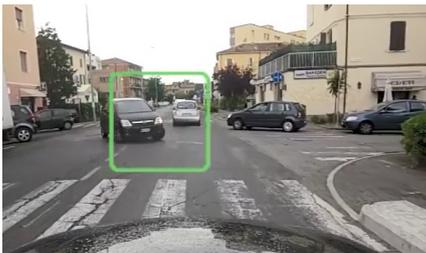


Figure 3: Bounding boxes as visual warnings used in XP3.

### 6.3 Quantitative Results

Regarding the interaction, we measured a similar number of pull requests in both experimental groups. Specifically, the group exposed to visual warnings and the group exposed to non-visual warnings had 5.33 and 5.57 pull requests on average, respectively. Again, visual warnings were positively correlated to

the higher cognitive load. The mean TLX score in the group containing visual warnings is generally higher (53.3), compared to the mean TLX score in a group without visual warnings (31.5). Mental demand, temporal demand, and effort were the dominant sources of workload (Table 6). The prototype used in XP3 scored higher on overall cognitive load compared to XP2. Also, we calculated the mean scores of the SEQ for each condition. The analysis revealed that it was easier to monitor the road situation and follow the warnings when there were no visual warnings (SEQ 5.78), compared to when the visual warnings are used (SEQ 4.89). Pearson's correlation shows that the TLX and SEQ scores are negatively correlated,  $r(7) = -.79, p < .05$  for the group with visuals, and  $r(7) = -.72, p < .05$  for the group without visuals.

Regarding UEQ, ATT score was 1.89 which confirms that participants generally liked the prototype. However, DP decreased significantly, indicating that users did not feel in control. Also, compared to XP2, EF also decreased significantly, confirming our finding that the system's reaction time was a little slow. Low PS score tells us that participants had difficulties getting familiar with the system, which is also reflected in the qualitative findings and confirmed by the fact that participants often tried unsupported tasks. Therefore, improving the pragmatic aspects of the prototype and evaluating it in a more immersive con-

text, would perhaps result in better UX. ST remained almost unchanged with a score of 1.58, meaning that participants found the system relatively fun to use. Although NV decreased to 1.29, we could conclude that the prototype scored well on hedonic qualities.

## 6.4 Qualitative Results

Table 5 presents the main findings from the thematic analysis. Generally, it was unclear for the participants how they should interact with the car. First, because they might not be used to voice interaction. Second, because they did not know what they should ask. However, participants still tried some unsupported features and commented on the car's driving style, often requested the car to slow down, tried control the speed or change the route. Lack of control frustrated some participants. They also expected the car to react to their negative feedback and thought that the car would learn based on it. Participants often asked why is the car making certain decisions, such as taking turns or giving way to other cars from side streets. Occasionally, they would not understand the warnings and would ask for an explanation from the car. In all conditions, except C4, there was one participant that did not record any interaction with the car. Additionally, some participants would just respond with simple "okay" or "thank you" when they heard the warning. This might indicate that at least a third of drivers are not willing to use their voice as a primary communication modality with their car.

## 7 DISCUSSION

We used the same experimental design in XP1 and XP2. We improved the prototype in XP2 based on the feedback received in XP1 and recruited the same participants to evaluate the changes. This choice resulted in receiving similar user feedback in both experiments. However, regardless of whether we performed the experiment remotely or in the lab, the results were accurate. Recruiting the participants matching the user profile of the target users rather than having the same participants would be a better methodological choice. First, it would compensate for the learning effects among participants between experiments. However, this is not always easy to mitigate, due to business or organizational constraints. Second, the purpose of formative evaluations is to test-and-refine prototypes based on the qualitative feedback received from small sample participants, not to check for statistical differences as is the case in experiments involving large sample participants. We recruited six partic-

ipants for each experiment, which complied with both the formative approach (Tullis and Albert, 2013) and our organizational constraints (time and budget).

In our UX evaluation, we administered three questionnaires to collect quantitative data, coupled with the laddering technique to collect qualitative data. Despite the richness of data collected, it made the experiments last long. For example, the TLX questionnaire requires a long administration procedure where the participants must read the instructions, identify the weights of each dimension, understand the rating scales well, and consistently recall their definitions throughout the study. This disrupted a consistent flow of the experiment and required the researcher to remind the participants of the meaning of the rating scales. Relying on the TLX Raw might be a better idea, as proposed in the literature (Hart, 2006). UEQ provides more useful information regarding the potential areas of improvement and it focuses on experiential qualities which we believe is important in exploratory phases of UX evaluation. Furthermore, video prototyping proved to be an efficient way to collect early feedback from target users regarding the warning modalities and the content of warning alerts.

We have not included the measurement of ecological validity in this work as it was out of the scope of our study. Ecological validity is the statistical correlation between a proximal cue and the distal variable to which it relates (Kieffer, 2017). In our study, the proximal cues refer to the traits or characteristics of the setting perceived by participants during the controlled experiments (e.g. driving on the highway), while the distal variables refer to the actual traits of the environment (e.g. watching a video of highway driving on a screen). As future work, we intend to compare the ecological validity between the three following experimental settings. First, the remote testing of video prototypes. Second, the immersive simulator studies in the lab. Third, driving a real car on the road. In particular, we will assess ecological validity by comparing participants' feelings of immersion between the three settings and participants' behavior between the three settings. This will allow us to assess the extent to which participants' experimental behavior corresponds to the expected functional behavior toward which we wish to generalize (Kieffer, 2017).

## 8 CONCLUSION

This paper presents a study on the UX design and evaluation of a senior-friendly warning system for autonomous vehicles. To that end, we created low-fidelity video-based prototypes and investigated sev-

eral combinations of output modalities to notify the driver about the road situation ahead. The analysis of qualitative and quantitative data shows that speech messages were effective in conveying the warning information to drivers. We also found that visual warnings are generally considered distracting and cause a higher workload. Still, participants see the visual warnings as a good backup to voice warnings. Voice interaction with a car seems to be a novelty to elderly drivers. Within a formative approach, we recommend recruiting new participants for each experiment while maintaining the sample size between 6 and 8 individuals in order to control the learning effect with the task and discover new design opportunities. Regarding standardized questionnaires, we found the usage of TLX and UEQ to gather information on the potential areas of improvement suitable to our domain. These findings, we believe, should be useful for practitioners and researchers involved in the design and development of features for semi-autonomous vehicles, such as voice-based interfaces, chat-bots, or road sign assistance.

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