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Drivers' acceptance of adaptive warning–monitoring systems. Findings from a car driving simulator study

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A R T I C L E   I N F O

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A B S T R A C T

Private vehicles are nowadays often equipped with advanced driver assistance systems (ADAS) that aim to assist drivers in maintaining safe driving behavior. Understanding users' acceptance and perceptions towards them is therefore crucial, mostly before developing or implementing additional assistance features. Driving simulators provide a unique opportunity to test ADAS in a controlled environment, in particular when safety–critical situations need to be replicated in a way that is not possible on real roads. In this study, an advanced warning–monitoring system, developed in the context of the recent European–wide naturalistic driving study (i–DREAMS[1]), is implemented in a driving simulator environment, so that is tested before it is then deployed in vehicles on real roads. For this purpose, a driving simulator study was conducted in Germany, in which 60 drivers participated. The study included three drives: the first was a baseline drive in which in–vehicle warnings were not activated, the second included real–time warnings (interventions), and the third had an additional distraction component, introduced by means of a mobile phone texting task (imposed on participants). Drivers were also asked to fill various questionnaires focusing on their perceptions towards general ADAS and driving, but also towards the implemented system (the i–DREAMS system[2]). A statistical analysis of the questionnaire results led to the partial validation of the technology acceptance model (TAM) for the i–DREAMS system, for which perceived usefulness (PU) and perceived ease of use (PEU) of the system, both of which resulted from a factor analysis of the attitudinal questions, were found to be crucial factors for the behavioral intention to use it. In the validated TAM, PU of the i–DREAMS system was found to be positively impacted by external variables, namely PU of similar ADAS systems, whereas PEU was found to be positively influenced by driving experience. While the system was overall positively received, findings and lessons learned from the experiment were transferred to future field experiments conducted within the same project, and suggested more generally that driving simulator studies could be very beneficial for testing newly developed in–vehicle technologies, leading on the long run to safer roads.

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[1] For more info on the project, please see: https://idreamsproject.eu/wp/.
[2] In the remainder of this paper, the tested system would be referred to as the "i–DREAMS system".

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1. Introduction

Each year, about 1.19 million people die as a result of road traffic crashes, costing most countries about 3 % of their gross domestic product. As a way to improve road safety and mitigate those crashes, the United Nations General Assembly has set an ambitious target of halving the global number of deaths and injuries from road traffic crashes by 2030 (World Health Organization, 2023). The European Union has also committed to similar goals, one of them being to move as close as possible to zero fatalities in road transport by 2050 (European Union, 2022). In the light of such ambitious goals, many initiatives have been promoted, including equipping vehicles with advanced driver assistance systems (ADAS) that aim to help drivers enhance their driving performance, improving thereby overall road safety. Accordingly, private passenger cars are becoming evermore modern, often equipped with ADAS. Well-known ADAS features include adaptive cruise control (ACC), forward collision warning (FCW), and lane departure warning (LDW) (Shaout et al., 2011). Among many reported benefits, ADAS have been shown to reduce highway crashes (Greenwood et al., 2022). An increasing research direction has therefore been to quantify the safety benefits and crash reductions resulting from ADAS usage. In a study in the UK, Masello et al. (2022) found that ADAS could reduce accident frequency in the UK by around 24 %, highlighting Automatic Emergency Braking (AEB) as the most impactful technology; the latter has been shown to potentially prevent about 50 % of rear–end crashes in a study by Jeong & Oh (2013). In estimating the effectiveness in crash avoidance of connected vehicle technologies and driver assistance technologies, Yue et al. (2018) found that FCW could reduce about 35 % of near–crash events under fog conditions, with a total maximum reduction of crash events of about 50 %. This study also revealed that the effectiveness was dependent on vehicle types (i.e., light vehicles vs. heavy–vehicles); however, rear–end crashes for both light vehicles and heavy trucks were found to have the most crash benefits from connected vehicles and driver assistance technologies. A more recent study by Yue et al. (2019) focused on assessing the effectiveness of different ADAS according to the roadway environment. The systems assessed included LDW, FCW, blind spot warning/lane change warning (BSW/LCW), intersection movement assist (IMA), pedestrian crash avoidance and mitigation (PCAM), and left turn assist (LTA) systems. The integrated system of the previously mentioned ADAS systems could prevent at most about 30 % of total crashes on urban multi-lane highways, while its lowest practical effectiveness was of 13.72 % on rural two-lane highways.

Yet, despite many reported benefits and advantages, ADAS may challenge the way drivers traditionally operate in vehicles. Similarly to other technologies, understanding the factors impacting ADAS acceptance is paramount, to be able to better advise on ADAS improvement, and accordingly enhance the levels of road safety. Only with higher ADAS acceptance can the potential benefits of these systems be fully unlocked, resulting therefore in much improved safety benefits. In understanding ADAS acceptance, previous studies focused on measuring drivers' reported perceptions of different ADAS, including the relation between acceptance and perceived ease of use, usefulness, or more generally knowledge about ADAS. This has been done as part of experimental studies, or as stand-alone surveys focusing on specific driver segments. For instance, Kaye et al. (2022) investigated the relation between knowledge about ADAS and ADAS acceptance, after which they concluded that more work was required to educate consumers about the functionality of ADAS. In this study, 56 % participants reported not seeking out information about ADAS prior to purchase. This could have influenced the perceived ease of use and usefulness of the system, as it might lead to a disparity between consumer expectations and the reality of the ADAS they have, and therefore, eventually, their acceptance of the system. A study by Greenwood et al. (2022) also showed how attitudes towards previous technology impacted driver accuracy of ADAS knowledge. Nandavar et al. (2023) also highlighted the importance of learning for influencing and improving experiences of drivers with ADAS (mostly through trial and error). Therefore, more generally, knowledge about ADAS is a factor that could directly or indirectly impact use and therefore acceptance of the systems. In a study by Stiegemeier et al. (2022), the authors highlighted the construct of "need" to be associated with perceived usefulness, and also highlighted "knowledge" and "habit" among other influencing factors. The latter could certainly be an interesting construct that could be investigated as part of external variables impacting ADAS acceptance. The findings of this study revealed subjectively important antecedents of the acceptance of in-vehicle technology and provided new insights, especially on usage barriers, which could be related to driving experience, and which has not been extensively investigated in previous research. Generally, perceived safety benefits have constantly been reported as key factors that driver consider when using ADAS (Biassoni et al., 2016; Nandavar et al., 2023; Pradhan et al., 2018).

In investigating such external variables and more generally drivers' behavior and acceptance of ADAS, previous research focused on drivers' reported self–assessments and perceptions of ADAS, based on their general driving experiences, often by means of surveys (Penttinen & Luoma, 2020; Kaye et al., 2022). Fewer studies assessed acceptance using experimental studies, in which data was collected including baseline driving (without ADAS), followed by driving in which ADAS were tested, after which participants reported their perceptions of the experienced systems. Among experimental or data collection studies, occasionally (and rarely) naturalistic driving studies have been used; however, as those are expensive and time–consuming, driving simulator experiments were more often used as well, to mitigate the barriers of the former and to allow researchers to test drivers' behaviors in low-risk environments that allow to test critical scenarios that cannot be otherwise tested on real roads. In this context, and while testing ADAS, to the best of the authors' knowledge, few studies, if any, assessed the acceptance of adaptive ADAS, such as the ones defined in Yang et al. (2024), as most studies and ADAS referred to systems that had fixed thresholds for various warnings or intervention systems. Moreover, few studies, if any, assessed the acceptance of adaptive ADAS which were part of a large–scale experiment, including both driving simulators and naturalistic driving studies, for which systems were tested first in a simulator environment before being tested on real roads. Finally, when thinking of acceptance, while common studies assessed ADAS perceived safety benefits in terms of perceived usefulness and perceived ease of use, implementing various acceptance models, few if any focused on the role of external variables on the acceptance, in particular that of driving experience. This study aims to fill these research gaps, by testing in a driving simulator environment, the acceptance of an adaptive in–vehicle warning monitoring system for private cars, developed within the European-wide naturalistic driving study i-DREAMS, tested first within the context of a driving simulator environment, and with a particular focus on driving experience as an external variable. The aim would be to eventually use these findings to better improve the designed system for real–road applications, but also to validate the factors impacting acceptance in such a context, such as the role of driving experience as an external variable. Accordingly, this papers' research questions (RQs) can be summarized as follows:

- **R.Q.1** What factors impact users' acceptance of a novel adaptive warning–monitoring system (notably the i–DREAMS system)?
- **R.Q.2** What is the impact of external variables on the acceptance of the above–mentioned system?
- **R.Q.3** Can participants' acceptance of the above system be represented by the classical technology acceptance model (TAM)?

In the remainder of this paper, we first provide an overview of related work (Section 2), to provide the necessary background for in–vehicle driving monitoring studies as well as the methods used to develop acceptance models. After that, an overview of the methodology followed in this manuscript is presented (Section 3), including the study design, study protocol and data collection, and data analysis and model development; at the beginning of this section, the objectives and hypotheses of the study are outlined. Then, in Section 4, the data collection and exploratory data analysis are presented, after which the model results are given in Section 5. Finally, in Section 6, the results are discussed, paving the way to the conclusion, answering thereby the research questions, and outlining possible future research directions.

2. Related work

2.1. ADAS acceptance

Previous research investigating ADAS has focused on understanding factors affecting drivers‘ acceptance towards such systems. For example, in a study by Xu et al. (2021), FCW was found to be more accepted than LDW, with obtained influencing factors for acceptance being vehicle speed, time of the day, and driver age. FCW and LDW effectiveness and acceptance were also investigated by Son et al. (2015) in the context of a real road experiment. In this study, drivers participated in field experiments with or without ADAS (particularly FCW and LDW), after which they were requested to fill a set of questionnaires. Findings from this study revealed the importance of age and gender differences in the effectiveness and acceptance for new in-vehicle technology.

In investigating cooperative systems offering fuel efficiency assistance, Höltl & Trommer (2013) found that these ADAS have the long–term potential to change driving behavior and thus have a sustainable impact to reduce fuel consumption and traffic emissions. This concept proved to be suitable for studying acceptance of intelligent transportation system (ITS) solutions aiming to save fuel. Perceived safety benefits was also shown to increase ADAS acceptance, and was found, along with pleasantness of use, to be the most important factor for novice drivers (Biassoni et al., 2016). Similarly, Viktorová & Šucha (2018) showed that perceived safety benefits increase driver acceptance, highlighting the need for a thorough driver education about the systems' functionalities.

Previous studies have used ADAS in a driving simulator context in order to improve the system based on the assessed acceptance of drivers' perceptions. Hegeman et al. (2007) designed a driving simulator study to assess the acceptance of an overtaking assistant design in a driving simulator experiment. Results from this study proved that according to the performance of the overtaking maneuvers, it is possible to design a standardized overtaking assistant. Similarly, van Driel et al. (2007) conducted a study in order to assess congestion assistant, within a driving simulator context, based on which some system refinements were suggested. Due to a relatively easier scenario design, as compared to real life, a previous study (Rossi et al., 2020) tested a lateral control ADAS, which informed the drivers whether the vehicle was correctly positioned inside the lane or not, with the use of two visual and one auditory stimuli. The ADAS were tested on three different groups, with different configurations: with no exposure to the ADAS, with exposure but without instructions, with exposure and with instructions. Findings suggested that the group receiving instructions and reading the information booklet was able to improve more and faster their lateral control, which highlights the importance of instructing drivers on the warning system for improving its acceptability.

2.2. Technology acceptance models

In modeling technology acceptance, various models have emerged over the years, with the Technology Accep- tance Model (TAM) by Davis et al. (1989), being one of the most renown ones to date. The latter was developed to investigate the relation between the intention to use and actual use of computer systems, and to develop a framework to model user acceptance in relation with factors that influence their decision to use the technology. The model main constructs include the perceived usefulness (PU), perceived of use (PEU) of the system, as well as a set of external variables. Following the development of this model, various model extensions have emerged, including the Technology Acceptance Model 2 (TAM2), which included variables grouped into social influence and cognitive processes (Venkatesh & Davis, 2000), affecting PEU. Another revision of TAM (Venkatesh et al., 2003) resulted into the Unified Theory of Acceptance and Use of Technology (UTAUT), and a later revision into TAM3 (Venkatesh & Bala, 2008); the UTAUT has been thought to offer a more complete account of acceptance in comparison with TAM2 (Ghazizadeh et al., 2012). In modeling acceptance of automation systems, trust was often found as a key factor impacting acceptance (Ghazizadeh et al., 2012; Zhang et al., 2019; Al Haddad et al., 2020).

To model ADAS acceptance, Rahman et al. (2017) used each of the technology acceptance model (TAM), the theory of planned behavior and the unified theory of acceptance and use of technology (UTAUT) to predict behavioral intention to use an ADAS, and found that TAM performed the best, explaining 82 % of the variability in behavioral intention. In this study, a fatigue monitoring system or an ACC combined with a lane-keeping system were tested, after which participants‘ perceptions towards these systems were tested, focusing on their usefulness and usability. Results of these studies confirm that the TAM can be applied to ADAS technologies to provide a basis for understanding driver acceptance. In a study by Cho et al. (2017), ADAS acceptance was tested using a driving simulator, in which different factors were found to affect the behavioral intention, namely: performance expectancy, social influence, perceived safety, anxiety, trust, and affective satisfaction.

2.3. Research gaps

While ADAS have become widespread and a few studies have previously looked at their acceptance, also using a driving simulator study, few if any have looked at state-of-the-art adaptive ADAS, i.e., ADAS that have dynamic thresholds for warnings and that adapt with varying real–time conditions. Moreover, in the developed acceptance models, while perceived usefulness and perceived ease of use have been considered key in many of these studies, few focused on external variables; the ones that did only focused on

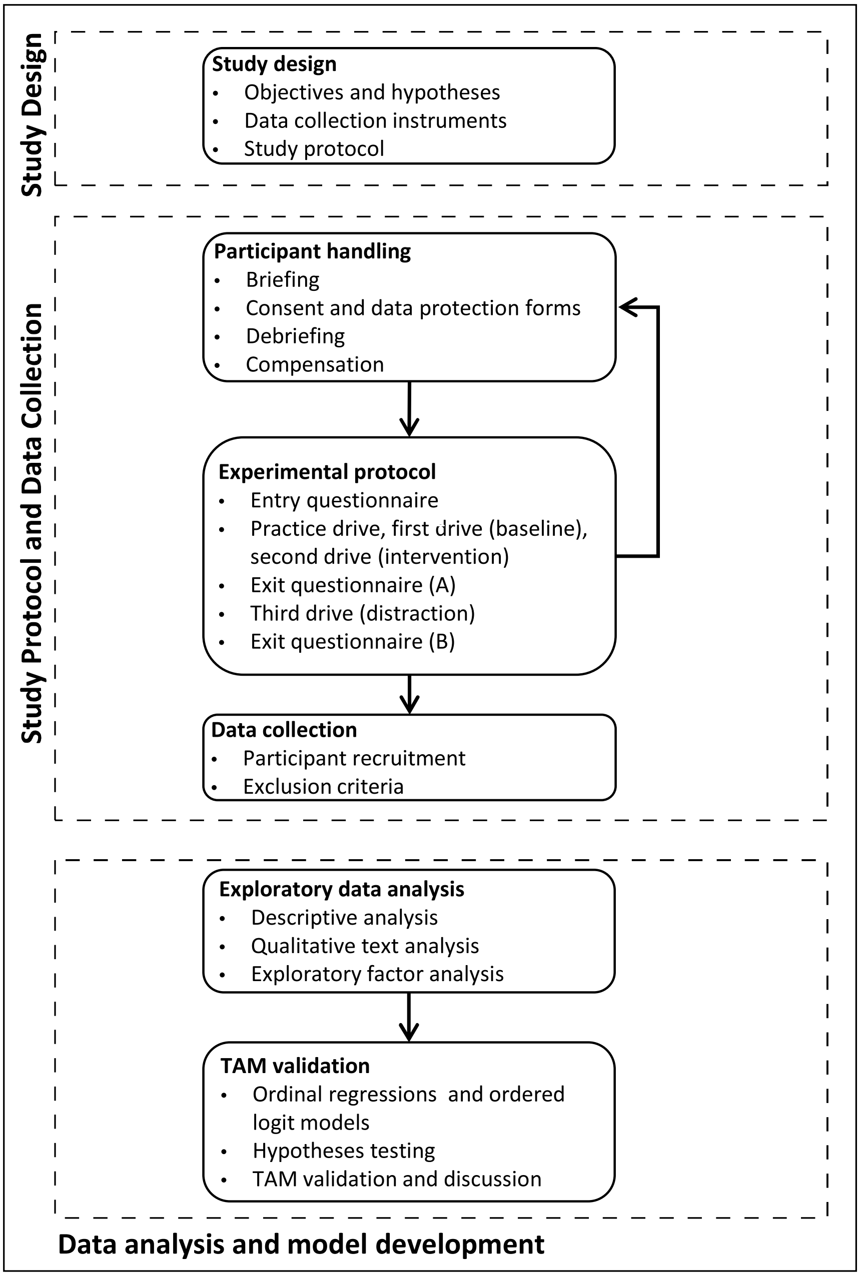

Fig. 1. Study methodology (*own illustration*).

socio–demographics such as age (Xu et al., 2021; Son et al., 2015) and gender (Son et al., 2015), or perceptions towards ADAS usefulness (perceived benefits such as in Biassoni et al. (2016)). However, few studies if any focused on notably driving experience and their impact on acceptance. Finally, to the the best of the authors' knowledge, previous studies have not assessed in a simulator system an ADAS that is part of a naturalistic driving study. This paper aims to therefore fill this above–mentioned gaps, by focusing on the acceptance of adaptive in–vehicle warning systems, with a particular emphasis on external variables.

3. Methodology

The methodology followed in this paper is presented in Fig. 1, and structured along following sub–sections: study design (sub–section 3.1), study protocol (sub–section 3.2), data collection (sub–section 3.3), and data analysis and model development (sub–section 3.4).

3.1. Study design

3.1.1. Objectives

In line with the larger scope project (i–DREAMS), this study aims to test a warning system for monitoring driver's behavior, to bring in the adequate interventions when operation is no longer within the safe boundaries. In particular, specific risk scenarios are tested, in a car–driving simulator environment. The experimental scenarios focused in particular on two risk factors: tailgating, and vulnerable road user (VRU) collision; for the latter, the focus was on potential pedestrian collisions. Additionally, the impact of distraction on different risk factors and critical events was investigated, across three drives. This paper will focus entirely on the questionnaire data that were collected before and after the completion of the experiments, in order to assess participants' prior perceptions and attitudes towards driving and ADAS in general, but also their experience with the i–DREAMS system.

3.1.2. Hypotheses

As mentioned above, the main goal of this study is to understand the perception of participants towards an adaptive warning–monitoring system (the i–DREAMS system) based on a driving simulator study conducted within

the i–DREAMS project. While several ways exist to model acceptance, the preferred and used method in this study is the technology acceptance model by Davis et al. (1989), as it has been proven by Rahman et al. (2017) to be the best among other models (such as the theory of planned behavior and the unified theory of acceptance and use of technology) in predicting behavioral intention to use ADAS. Therefore, several hypotheses will be tested along the lines of this model, as depicted in Fig. 2, and denoted as H_1, H_2, and H_3 (hypotheses 1, 2, and 3, respectively).

These hypotheses aim to test the following:

1. H_1: $BI = f(, P\,EU)$.

This hypothesis postulates that behavioral intention to use the ADAS (in the case of this study, the i–DREAMS system) is a function of its perceived usefulness (PU) and perceived ease of use (PEU); these two constructs would be extracted by means of a confirmatory analysis using questionnaire variables for the i–DREAMS system acceptance. In particular, for this study, the behavioral intention to use the system refers to the intention to continue using the system if given the choice, which is based on and obtained from, exclusively, the questionnaire data.

2. H_2: $PU = f(P\,E, \textit{external variables})$.

This postulates that the system's perceived usefulness is a function of its perceived ease of use and of external variables. External variables here could be gender, other demographics, ADAS use, or other perceptions towards ADAS and other driving habits or driving history; the aim of this hypothesis is therefore to understand and unveil those external variables.

3. H_3: $P\,EU = f\,(\textit{external variables})$.

This means that the system's perceived ease of use is a function of external variables; the aim here is also to identify those variables.

3.1.3. Data collection instruments

Instruments used in this study in order to conduct the experiment and collect data are represented in Fig. 3.

Data collection instruments used in this experiment are detailed as follows.

- Fixed based driving simulator based on a Peugeot 206, including a dashboard, adjustable driver seat, steering wheel, accelerator, brake and the i-DREAMS system amongst other components; it was developed by DriveSimSolutions (https://www.drivesimsolutions.com/) and operates on STISIM Drive 3. Three 49″ 4 K monitors with a 135° field of view are used to simulate the driving environment.
- Mobileye, a context aware road monitoring system (https://www.mobileye.com/), an off-the-shelf ADAS system that has been configured with the driving simulator to trigger real-time warnings. For the purpose of the i–DREAMS experiments, the algorithms and thresholds have been adapted to be dynamic and were displayed on a customized display (the intervention device instead of the commercially available EyeWatch commonly used with Mobileye). Mobileye's purpose was to measure driving performance parameters like headway distance, in addition to triggering interventions like the Forward Collision Warning (FCW) and Pedestrian

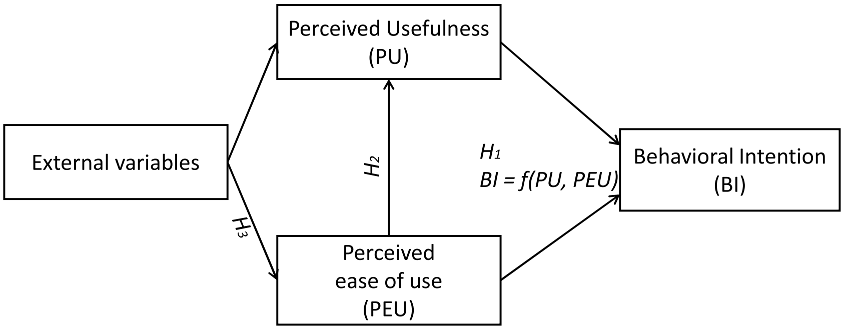

Fig. 2. Hypotheses to be tested within the TAM (own illustration, adapted from Davis et al. (1989).

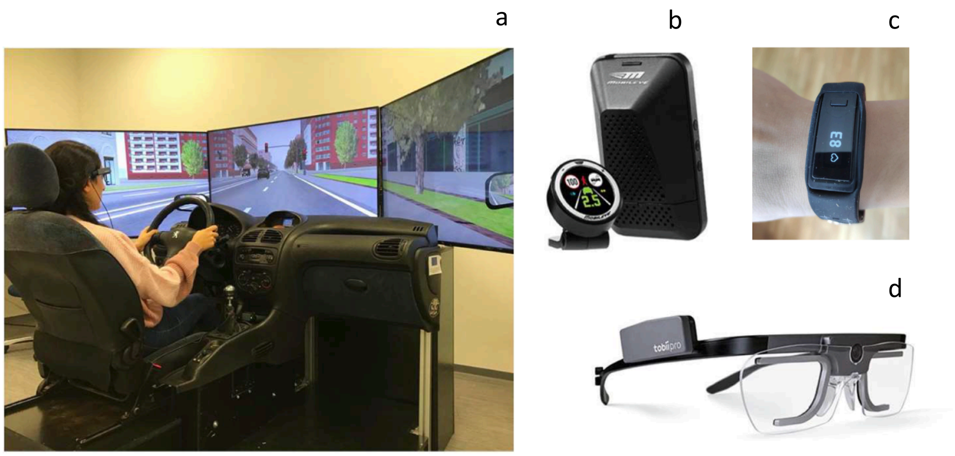

Fig. 3. Data collection instruments. a-Fixed driving simulator setting; b-Mobileye system; c-PulseOn wearable, d-Eye–tracking glasses.

Collision Warning (PCW), and consequently collecting this information during each drive. Moreover, distraction warning for cell phone usage was also added as a warning, based on pre–determined distances corresponding to the imposed distraction in the experiments. Despite the latter not being a real–time warning like the previous ones, it was added to test participants' feedback to it. Warnings that were triggered in this experiment are summarized in Fig. 4.

- A gateway, used as a central communication component to send the data it collects and calculates back to the driving simulator in real-time through a serial interface. The data from the gateway is synchronized and combined with simulation variables and stored locally on the simulator PC. Just as in the real vehicle, the i-DREAMS gateway is responsible for triggering real-time interventions.
- A wristband– PulseOn wearable (https://pulseon.com/)– to monitor heart rate and related variables.[3]
- Eye-tracking glasses– Tobii Pro Glasses 2 (https://www.tobiipro.com/) – to collect eye movement data.
- Questionnaires: an initial recruitment questionnaire, an entry questionnaire (completed before the first drive), and two exit questionnaires, completed at different stages of the experiment.

3.2. Study protocol

3.2.1. Participant handling and experimental protocol

Participant handling ensured that all necessary forms were filled by participants, in order to comply with the ethical, and data protection regulations that are necessary for this type of study. In particular, participants were first briefed about the experimental set–up, after which they filled a consent form (for their approval to take part of the study, which was voluntary) and a data protection form (for their consent to allow the processing of their data for research).

Participants then filled an entry questionnaire, assessing their initial attitudes about driving and ADAS percep- tions (prior to taking part of the experiment). After that, they drove a first practice drive to familiarize themselves with the driving simulator itself. In this drive, the eye–tracking glasses were calibrated to the participants. Then, the first two drives were completed. The first drive was a

[3] In the simulator, the Mobileye camera, the wristband and the simulator software itself are used as sensors to capture data in real-time.

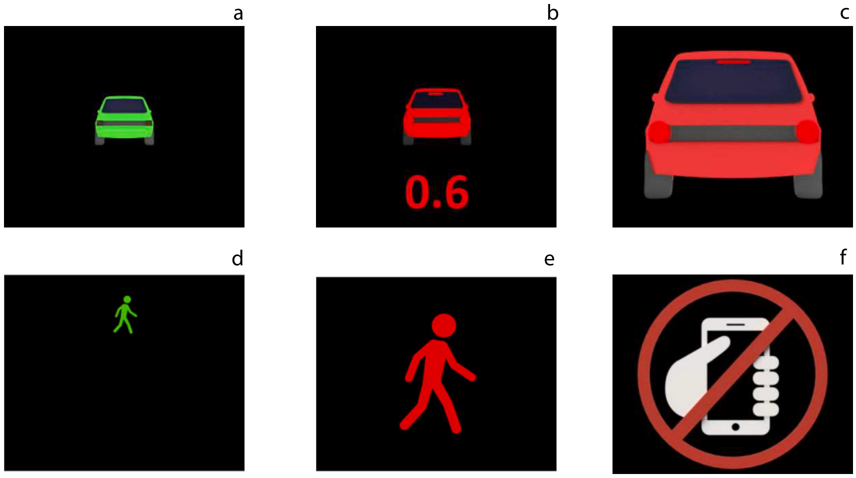

Fig. 4. Warnings symbols: a- Vehicle detected ahead (normal driving); b- Vehicle ahead is too close. Time headway is displayed in seconds (0.6). Flashing icon, accompanied by auditory signal; c-Forward collision warning: flashing icon accompanied by auditory signal; d-Pedestrian detected in danger zone; e- Pedestrian is imminent. Flashing icon, accompanied by auditory signal; f- Distraction warning by smartphone usage.

baseline drive, during which no warnings were triggered, and which aimed at collecting baseline data that could be used as control data for future analyses looking at the impact of interventions on driving behavior. The second drive was a drive with **interventions**, during which real–time warnings were triggered. After that, the first exit questionnaire (Exit A) was completed, to assess participants' perceptions towards this warning (the i–DREAMS) system, having completed the first two drives. Finally, in the third drive, **distraction** was imposed on participants, as they were requested to read and respond to text messages. For all three drives, participants were wearing eye–tracking glasses. The aim was therefore to benefit from eye movement data to better understand distraction. After the last drive, participants filled the final questionnaire, aiming at assessing one more time participants' perceptions towards the warnings and their effectiveness. After completing the experiments and the questionnaires, participants were given a de–briefing form, informing them that texting while driving was only part of the experiment, stressing out that using the phone while driving was by no means acceptable on the roads. This was done however after the completion of the experiments, and not before, in order not to bias participants' behavior for the distraction scenario. At the end of the experiment, participants were given a compensation for their participation in the experiment.

3.2.2. Scenario design

As previously mentioned (sub–section 3.1.1), this study primarily investigates the impact of the designed adaptive ADAS, focusing on two risk factors, i.e., tailgating and pedestrian collision. The scenarios were designed across three drives: a baseline drive (without any warnings), an intervention drive (with the warning systems activated), and a distraction drive (warnings activated); for the latter (third drive), participants were asked to drive as before, with the additional task of reading and responding to text messages using a smartphone. For each of the tailgating and potential pedestrian collision risk factors, three critical events were designed (identical across drives), and randomized across three road environments: rural, urban, and highway. For the distraction drive, in total, six text messages were triggered before each of the six critical events, and two when there was no event. The overall order of scenarios and events was randomized among the participants and during the trials and is described in Amini et al. (2021). The critical events (CEs) for each of the risk factors can be summarized in Table 1 as follows.

3.3. Data collection

Participants were recruited through various channels: online (social media, websites, mailing lists, etc.), but also offline (posters with the necessary information). The aim was to recruit a sample representative of Munich's driver demographics. However, as the latter was not available, it was then changed to a sample representative of Munich's population. Necessary criteria included the following: having a valid driver's license, not wearing glasses during the experiment (contact lenses were acceptable; glasses were not preferred), and not having had previous ophthalmic surgeries (the last two points were considered in order not to interfere with the data collection using the eye–tracking glasses).

As mentioned earlier, data collected in this experiment includes simulator data, Mobileye data, wristband data, eye–tracking data, and questionnaire data; however, in this paper, to assess acceptance, the focus was only given to the questionnaire data (extracted from the various questionnaires). It is important to note that attitude and agreement statements were all presented in the form of 5–point Likert scale statements (Likert, 1932). The data extracted across the questionnaires is summarized in Table 2 below. Here, it is important to highlight the difference between questionnaire variables referring to respondents' perceptions of ADAS (a priori perceptions of ADAS that they might or might not have experienced in the past, irrespective of the simulator experiment they participated in) and their perceptions of the i–DREAMS system (the adaptive in–vehicle warning monitoring system they experienced in the

Table 1
Summary of critical events.

Risk factor	Critical event	Scenario description
Pedestrian collision	CE 1	A pedestrian crosses the road illegally (jaywalking) when the driver is approaching the intersection on the green phase.
	CE 2	At a mid-block crossing, a pedestrian –initially obstructed from the driver's view by a bus starts crossing the road while the driver is approaching.
	CE 3	A pedestrian crosses the road at the uncontrolled crossing while the car is approaching.
Tailgating	CE 1	A car is driving at low speed in front of the driver, while the available gap in the opposite traffic is not sufficient for an overtaking maneuver.
	CE 2	A car overtakes the driver and suddenly merges into the lane in front of it with the result that the driver needs to adjust the driving speed.
	CE 3	A car enters the highway in front of the driver, with the result that the lead car needs to make a harsh brake.

Table 2
Variables extracted per questionnaire.

Questionnaire	Variables extracted
Recruitment questionnaire	Participants demographics (age, gender, etc.)
Entry questionnaire	ADAS frequency of use, ADAS use Attitudes towards ADAS Agreement statements regarding distraction engagement, History of accident involvement, fines for traffic offenses
Exit questionnaire A	Attitudes towards the i-DREAMS system mostly based on Rahman et al. (2018)
Exit questionnaire B	Open–ended questions about the strengths of the system, the points to improve, but also a description in short words of the system Clarity of the system, including overall clarity, visual clarity, and sound clarity

experiment).

3.4. Data analysis and model development

An initial exploratomyry analysis was conducted as follows:

- Descriptive analysis: extracting the main statistics of questionnaire variables such as demographics and attitudes and perceptions. The impact of demographics on participants' perceptions and attitudes (e.g. gender) was also assessed, by conducting Chi-square tests and extracting variables that were significant at a 95 % level of confidence.
- Qualitative analysis: to further interpret the open–ended questions to explore participants' experiences with the used system.
- Confirmatory factor analysis: to validate the hypotheses set out in the manuscript (see Fig. 2); this analysis used the maximum likelihood estimation method as a factor extraction method. Moreover, a scree test was performed to determine the optimal number of factors, and since the factors were assumed to be uncorrelated,

  varimax orthogonal rotation was used (Kaiser, 1958). Factor scores were then computed using a weighted sum of the factor loads.

- TAM validation and discussion: the manuscript hypotheses were tested to understand the different relationships pertaining to the perception of the i–DREAMS system within the scope of the conducted experiments. This was done using Ordinary Least square (OLS) regression, and Ordered Logit Models (OLM), for continuous and ordered-discrete variables respectively.

Table 3
Socio–demographics characteristics of sample data (N = 60).

Variable	Statistics
Gender: Male	25 (42 %)
Gender: Female	35 (58 %)
Age	30 (26, 37)
Driver's license duration (years)	9 (6, 15)
Vision impairment (No)	43 (72 %)
Vision impairment (Yes, wore contact lenses)	14 (23 %)
Vision impairment (Yes, did not wear glasses nor contact lenses)	3 (5 %)

4. Data collection and exploratory data analysis

4.1. Sample characteristics

The recruitment resulted in the selection of 60 suitable participants, who successfully took part in the driving simulator experiments. This section presents the demographics of these participants, including gender, age, driver's license duration (meaning the number of years since a participant has obtained his or her license), and vision impairement (as it was a requirement resulting from the use of the eye–tracking glasses). Table 3 below summarizes these demographics, for which average and percentage are provided. For age and driver's license duration, median and interquartile range are also given. Beyond these variables, the entry questionnaire reflected that most participants did not have ongoing medical problems (97 % of participants), nor have had previous accidents (93 %), nor fines (only 31 % of participants have had one or more fines in their lives–particularly 30 % of those were overspeeding fines).

4.2. Exploratory data analysis

4.2.1. Descriptive analysis

Based on the questionnaire responses, participants' attitudes and perceptions were assessed. Summary statistics including mean, standard deviations (std), minimum (min.), maximum (max.), and median of the different variables are presented in Tables A.10 to A.12 in Appendix A. Moreover, gender was investigated, in order to see whether it had an impact on some of the variables (based on Table 3, as it was the only categorical variable with a rather balanced distribution: 42 and 58 % for females and males, respectively). Overall, the Chi-square tests showed that gender did not impact significantly the constructs of ADAS presence, frequency of use, perceptions towards ADAS, distraction engagement while driving, and towards the i-DREAMS system. In the below section, participants' attitudes towards ADAS, towards the i–DREAMS system, but also their perceptions of the system's clarity, are presented (Figs. 5 to 7, respectively). For the agreement statement plots, an aggregation over all participants was presented, with average values for the different statements. Only when significant, a differentiation by gender is shown.

The entry questionnaire revealed participants' attitudes towards ADAS in general, with insights on their perception of ADAS usefulness, ease of use, but also potential distracting effect they might have on driving. Fig. 5 presents a summary of these findings for the different statements, which had five response options, ranging from "strongly disagree" to "strongly agree". For the below summary, the term "agree" will be used as a simpler way to refer to both answer options "strongly agree" and "agree", whereas the term "disagree" would be used as a simplification for "strongly disagree" and "disagree".

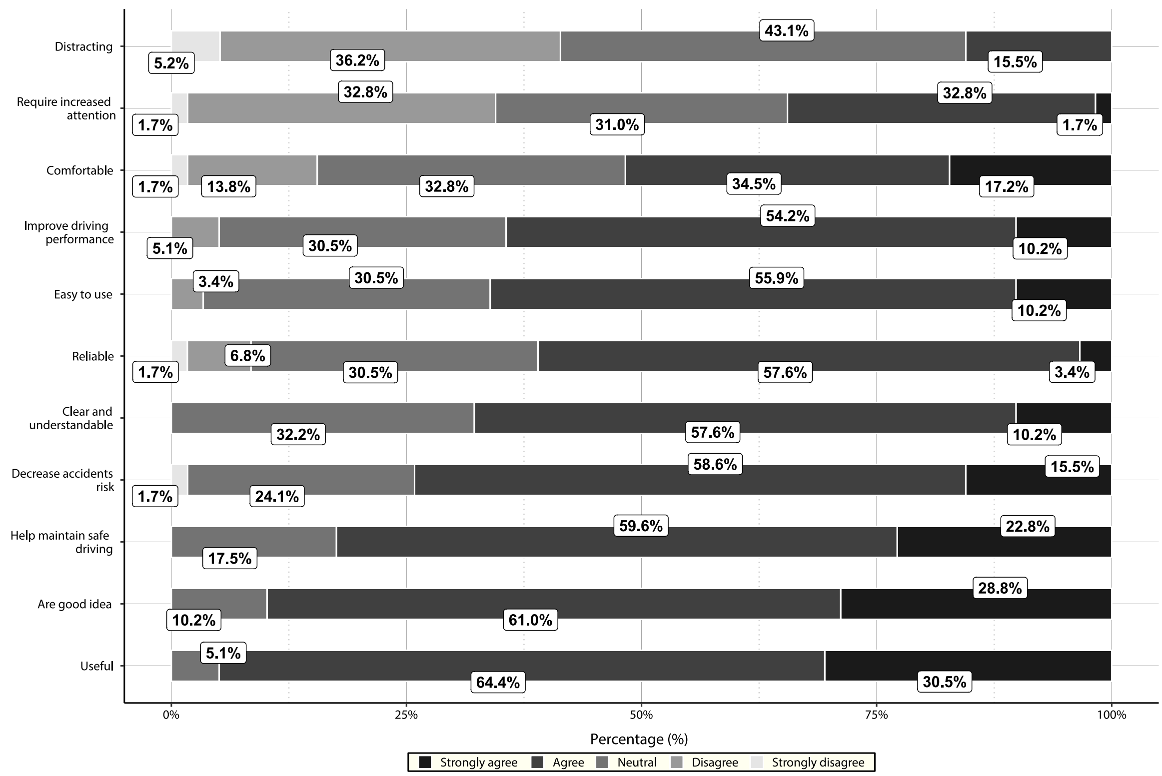

Fig. 5. Participants' overall attitudes towards ADAS (N = 60).

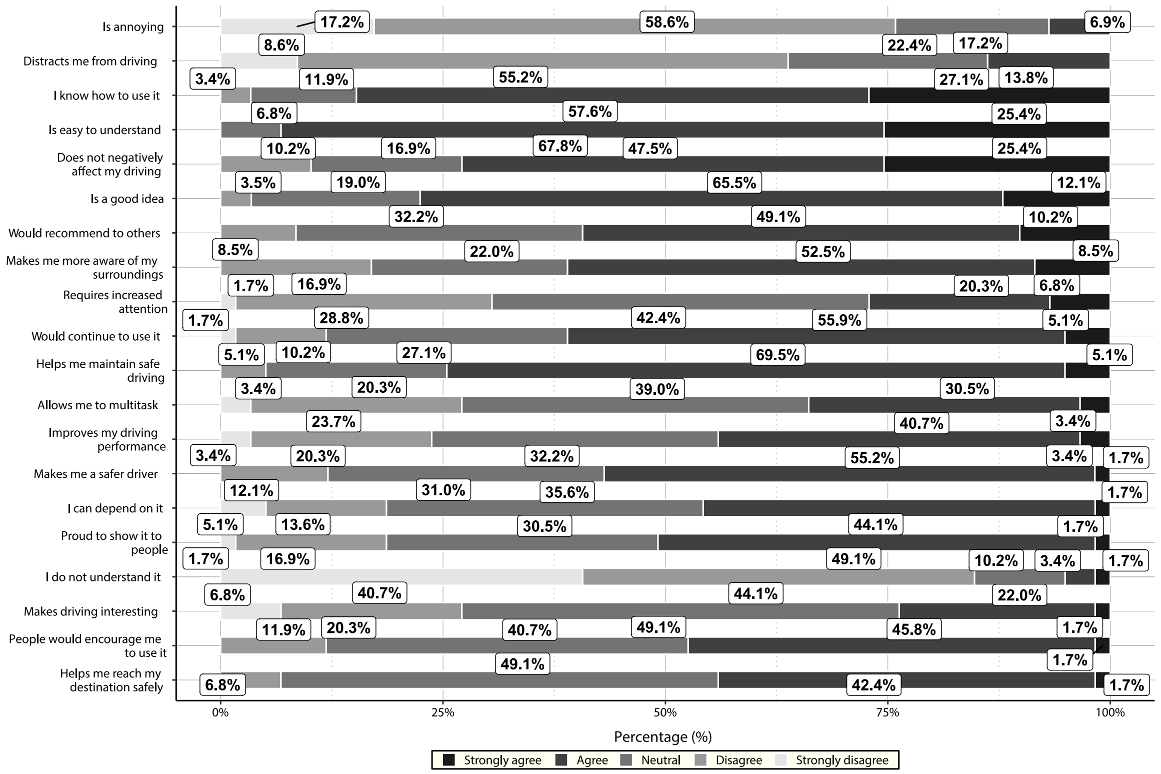

Fig. 6. Participants' overall attitudes towards the i-DREAMS system (N = 60).

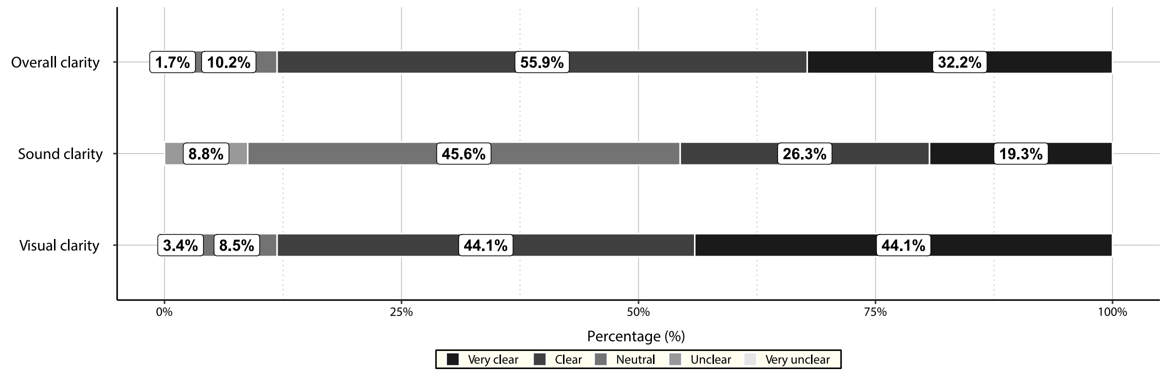

Fig. 7. Participants' overall perceptions of the i–DREAMS system clarity (N = 60).

In general, most respondents seemed to agree that ADAS are useful (about 95 %) and are a good idea (about 90 %), and that they have benefits [help maintaining safe driving (above 80 %), decrease accident risk (above 70 %)]. The majority also seemed to trust the information received from ADAS (above 60 %), and feel comfortable doing other things with ADAS (above 50 %). Moreover, most respondents found ADAS information clear and easy to use (above 65 %). Overall, participants had therefore rather positive towards ADAS, with only a lower percentage believing that ADAS itself might be distracting (about 15 %) or might require increased attention (less than 15 %).

Fig. 6 presents a summary of the findings of participants' attitudes towards the i–DREAMS system, based on the first exit questionnaire (A), collected after the first set of driving experiments. The main findings suggest that participants mostly agreed that the i–DREAMS system is a good idea (about 80 %), which helps them to maintain safe driving (about 75 %) or reach their destinations safely (also make them safer drivers– above 50 %), and allows them to multi-task while driving. Most participants would rely on the system, believe that the system would make them more aware of their surroundings, would recommend it to others, and would continue using it if given the choice (about 60 %).

Moreover, most seemed to agree that the system is easy to use (about 85 %), and that they have the necessary knowledge to use it (above 80 %). A lack of consensus however was found on whether or not the system required increased attention (about 45 % neutral), and whether participants would be proud to show it to others (about 30 % neutral), or whether they believed others would encourage them to use it (above 40 % neutral). Finally, most seemed to disagree that it distracts them (about 65 %), annoys them (about 75 %), or negatively affects their driving performance (above 75 %).

Overall, perceptions towards the i–DREAMS system were quite positive, with participants believing it to be useful and easy to use (above 80 %); however, overall, the level of acceptance seemed to be rather lower than the one of ADAS in general, shown in Fig. 5, which makes sense since the latter refers to participants' overall ADAS perceptions, based on systems they are already familiar with, while the current study addresses the perceptions towards a customized system: the i–DREAMS system.

Fig. 7 presents a summary of the findings on participants' perceptions of the i–DREAMS system clarity.

Overall, 88 % of participants found the system generally clear (a combination of "very clear" and "clear" answer options). Similarily, 88 % of participants found the system to be visually clear (based on the visual symbols). On the other hand, only 45 % found the sounds of the i–DREAMS system to be clear. The results of this part reflect the findings from the qualitative analysis, in which respondents indicate that they understand the system overall, mostly the visual components, but also indicate some limitations or improvement potentials in the sounds of the different warnings.

Additional plots regarding ADAS availability, frequency of use, and further attitudinal statements (regarding driving and distraction) are presented in Appendix A.2.

4.2.2. Qualitative analysis

In this section, a qualitative analysis is presented based on open–ended questions of the questionnaires (Exit A and Exit B). These concern the main strengths of the system, the recommended improvements, the general impressions about the system (positive and negative keywords), and finally the system clarity. Most participants found the system to be quite useful, as it helped them maintain safe driving. It was also perceived as useful, easy to understand, and user–friendly. Visual graphics were clear, auditory sounds were understandable, and the simulator design was realistic. Finally, the time indication (time to collision) was found very useful and quick (to alert).

Visually, the system was clear to understand. Further improvements were concerned with the display screen where the warning systems were displayed, as it was perceived to be too far away: changing the location or increasing it could improve the system. With regards to the sound assistance, more sounds or a voice notification (voice–over) announcing warnings, including over–speeding or danger alerts, could be useful in completing sound effects, and would improve clarity.

Despite the overall clarity consensus, some drivers did not seem to understand the numbers on the pictograms (seconds to collisions), and suggested to have them replaced by the corresponding distance. Some even suggested to remove numbers generally. This may indicate that a longer testing phase might be needed, during which warnings could be explained and drivers could be exposed to them, which would be consistent with the findings by Rossi et al. (2020) on the importance this might bring for the system acceptability. However, this may lead to biases in driving performance and evaluation and in scenario predictability.

5. Modeling results

5.1. Factor analysis results

This section presents the results of the factor analysis applied to the attitudinal statements with same–scale response answers (ordinal 5–point Likert scale) resulting from the questionnaires.[4] As mentioned in the methodology (Section 3), an orthogonal rotation was used. Variables for which loadings were higher than 0.4 were retained; the factor analysis reduces the factors to fewer factors, each explaining more than 20 % of the variance [considered acceptable according to Costello & Osborne (2005)]. For both factor analyses presented below, a cumulative variance of about 50 % was reached.

A first factor analysis aimed to reveal patterns behind participants' overall attitudes towards ADAS (resulting from the entry questionnaire); the factor analysis applied to the constructs presented in Fig. 5 gave insights to the results presented in Table 4. Essentially, the main factors were extracted, with interpretation as follows: ADAS ease of use and ADAS usefulness. The former is a combination of "easy to understand" and "clear and understandable" (accounting for 27 % of the data variance), while the latter is a combination of "useful", "reduces accident risks", and "trust ADAS information" (accounting for 21 % of the variance); the cumulative variance represented by both factors corresponds to 48 %.

Further in the entry questionnaire, a set of questions highlighted participants' prior perceptions of (and actual) distraction engagement. The results of this factor analysis are summarized in Table 5. Distraction attitudes can be grouped under two main factors. The first factor corresponds to engagement in secondary distraction, grouping the belief of being able to drive well while eating or drink and while conversing with passenger, and the perception that it is okay to drive while eating or drinking, with the perception that these activities are distracting (for the latter construct, the opposite sign, or negative sign, was seen, which makes sense since it is the opposite direction than the other constructs). This factor represents 30 % of the data variance.

The second factor corresponds to phone distraction, which combines a set of factors on beliefs and perception of driving well or

[4] For the data used, the Barlett's test of sphericity resulted in significant values up to the 95% level of significance, indicating that they were suitable for a factor analysis.

Table 4
Factor analysis results for respondents' perceptions of ADAS.

Loadings	Factor 1	Factor 2
ADAS are easy to understand	0.84	
ADAS are clear and understandable	0.77	
ADAS are useful		0.70
ADAS reduces accident risks		0.61
I trust ADAS information		0.41
Sum of square of loadings	1.34	1.05
Proportion variance	0.27	0.21
Cumulative variance	0.27	0.48
Factor interpretation	ADAS ease of use	ADAS usefulness

Table 5
Factor analysis results for respondents' overall attitudes on distraction engagement.

Loadings	Factor 1	Factor 2
Believe to drive well while eating and\or drinking	0.91	
Believe to drive well while conversing with passengers	0.71	
Think it is okay to drive while eating andor drinking	0.62	
Find it distracting to drive while reading roadside advertisements	−0.50	
Find it distracting to drive while conversing with passengers	−0.64	
Find it distracting to drive while eating andor drinking	−0.71	
Believe to drive well while conversing with the phone		0.56
Believe to drive well while interacting with the phone		0.61
Think it is okay to drive while interacting with the phone		0.73
Think it is okay to drive while conversing with the phone		0.86
Sum of square of loadings	3.03	2.08
Proportion variance	0.30	0.21
Cumulative variance	0.30	0.51
Factor interpretation	Secondary distraction	Phone distraction

thinking it is okay to drive while interacting with the phone, or conversing with the phone. This factor represents 21 % of the variance. In total, both factors represent about 51 % of the variance.

Finally, a (confirmatory) factor analysis was applied to the variables resulting from agreement statements presented in Fig. 6, based on Exit questionnaire A; results for this analysis are presented in Table 6. However, for this factor analysis, the different constructs on the i–DREAMS system perception were used except the variables on the intention to further use it or to recommend it to others, since both would be used as dependent variables to test the hypotheses presented in Fig. 2.

The variables for this section were grouped under two main factors: i–DREAMS perceived usefulness and i–DREAMS perceived ease of use, representing 31 % and 14 % of the total variance, a cumulative 45 % of the data variance. The former factor was a combination of various constructs including the system's usefulness, such as that it is a good idea, it makes drivers more aware of their surroundings, it makes them safer drivers, improves their performance, etc. For the second factor, this corresponded to constructs on the ease of use of the system: also, it has a negative loading for the third construct ("I am afraid I do not understand the system"), which makes sense as it

Table 6
Factor analysis results for respondents' perceptions of the i–DREAMS system.

Loadings	Factor 1	Factor 2
Using the i–DREAMS system is a good idea.	0.72	
Using the i–DREAMS system makes me more aware of my surroundings	0.69	
The i-DREAMS system makes me a safer driver	0.69	
The i-DREAMS system improves my driving performance	0.66	
I would be proud to show the i-DREAMS system to people close to me	0.65	
While using the i-DREAMS system, I can maintain safe driving behavior.	0.62	
People who I like would encourage me to use the i-DREAMS system	0.59	
Using the i-DREAMS system, I will reach my destination safely	0.55	
The i-DREAMS system makes driving more interesting.	0.55	
I have the knowledge necessary to use the i-DREAMS system.		0.77
I think the i-DREAMS system is easy to understand		0.50
I am afraid that I do not understand the system.		−0.71
Sum of square of loadings	3.68	1.71
Proportion variance	0.31	0.14
Cumulative variance	0.31	0.45
Factor interpretation	i–DREAMS system perceived usefulness	i–DREAMS system perceived ease of use

is opposite in meaning than the other variables this factor is based on.

Having obtained the factor analysis results summarized in Tables 4, 5, and 6, new factors scores were generated as a linear combination of the factor loadings and variables for which the factors loaded, using a weighted sum of the factor loads.

5.2. Hypotheses models

In this section, the results of the models developed to test the hypotheses laid out in Fig. 2 are presented. To test the first hypothesis (H_1), i.e., that the intention to use of the i–DREAMS system is a function of its perceived ease of use and perceived usefulness, the "usage" variable ("I would continue to use the i–DREAMS system) was used for the "behavioral intention" (BI) of the technology acceptance model. For the independent variables, or in other words the perceived ease of use (PEU) and perceived usefulness (PU) of the system, the newly generated factors resulting from the factor analysis presented in Table 6 were used. Since the dependent variable here "usage" is a discrete outcome with answer options ranging from "strongly agree" to "strongly disagree", or in other words ordinal discrete responses, this hypothesis was tested by developing an ordinal logit model with the variables mentioned (usage as dependent variable, ease of use and perceived usefulness as independent variables). For this model, and since the responses were unbalanced, the five answer options were regrouped in three categories: disagree (including "strongly disagree" and "disagree"), neutral, and agree (including "strongly agree" and "agree"). The model results are presented in Table 7.

Results of the above model highlight that the behavioral intention to use the i–DREAMS system is highly impacted by its perceived usefulness and its perceived ease of use, as both factors were found to be strongly significant (95 % confidence level). The positive signs also indicate that the higher the perceived usefulness and perceived ease of use of the i–DREAMS system, the higher the chance of intending to use it in the future, which is in line with the first hypothesis (H_1).

For the second hypothesis (H_2), PU is used as a dependent variable and its relation with each of PEU and other external variables are tested. Among many external variables, socio–demographics including age and gender, and attitudinal traits (resulting from previous factor analyses) were used. Due to the continuous nature of PU, the newly generated factor from the factor analysis presented in Table 6, an ordinary least square regression model was developed to test the second hypothesis. After testing different independent variables, including PEU and various external variables, the best performing model (Table 8) was only able to highlight the significance of ADAS perceived usefulness (a priori perception of ADAS usefulness, generated from the factor analysis in Table 4) as one of the external variables in this second hypothesis. Moreover, the model results could not indicate a strong and significant relationship between the perceived usefulness and perceived ease of use of the i–DREAMS system. This means that the second hypothesis is only partially validated.

Finally, the third hypothesis (H_3) was tested. As external variables, gender was used, along with other demo- graphic variables (among which the newly obtained factors from the different factor analyses presented in Tables 4 and 5), indicating participants' attitudes and perceptions towards ADAS or distraction engagement in relation to driving performance. To examine this relation, and since the perceived ease of use is a continuous variable (whose values were computed as a linear combination of the factor loadings and different variables as per the factor analysis results), an ordinary least square model (OLS) was also developed. The results are presented in Table 9, with significant estimates up to the 95 % confidence level presented in Bold.

Results presented in Table 9 highlighted the impact of only one external variable in relation to the i–DREAMS' system perceived ease of use, which is the duration or time period for which the participant has obtained his or her driver's license. In particular, this negative relation indicates that the higher this duration is, the lower is the perceived ease of use of the i–DREAMS system. This could be attributed to the fact that the higher the license duration, the older the participants, and therefore the (possibly) lower affinity to newer technologies, which could explain the negative correlation with the perceived system ease of use. Still, this means that hypothesis 3 is validated, as external variables such as the license duration significantly impacted the system's perceived ease of use.

6. Discussion and conclusions

6.1. Discussion

Following the methodology elaborated in Section 3, this study resulted in the completion of a driving simulator experiment, in which 60 participants completed the required driving tasks, including filling out questionnaires in different stages of the experiment. These questionnaires reflected on their feedback about the adaptive warn- ing—monitoring system (the i–DREAMS system) that was the focus of the study in question. As mentioned, the main objective of these questionnaires was to get participants' feedback at

Table 7
Ordered logit model (OLM) results for the first hypothesis [i–DREAMS system BI (N = 60)].

Variable	Estimate	t–test
i–Dreams system PU	2.11	4.63
i–Dreams system PEU	0.66	2.04
Disagree | Neutral	−3.41	−5.11
Neutral | Agree	−0.59	−1.60
Log–likelihood = -34.7		
AIC = 77.5		
BIC = 85.8		

Table 8
Ordinary least squares (OLS) results for the second hypothesis [i-DREAMS system PU (N = 60)].

Variable	Estimate	t–test
Intercept	−0.010	−0.083
ADAS PU	0.33	2.67
R squared	0.11	
Adjusted R squared	0.09	

Table 9
Ordinary least squares (OLS) results for the third hypothesis [i–DREAMS system PEU (N = 60)].

Variable	Estimate	t–test
Intercept	0.41	2.08
Driver's license duration (years)	−0.034	−2.65
R squared	0.11	
Adjusted R squared	0.09	

different times of the experiment: their initial perceptions of ADAS, driving, and distraction while driving (entry questionnaire before the experiments started), their feedback about the i—DREAMS warning monitoring system (exit questionnaire A- after completing the second-intervention drive), and their feedback about the overall i–DREAMS system (exit questionnaire B- overall clarity, visual and sound clarity).

The overall attitudes of respondents towards ADAS (Fig. 5) indicated that participants tended to have overall positive perceptions of ADAS, meaning that they mostly (over 90 %) thought it was useful (good idea, has benefits like maintaining driving safety), trusted it (above 60 %), but also found the information they provided to be clear and understandable (about 65 %); in general, very few participants thought of ADAS to be distracting (about 15 %). Similarly, for the i—DREAMS system (Fig. 6), most participants (above 75 %) seemed to find it useful (to maintain safe driving), indicating an overall high level of trust with regards to the system, stating that they would keep using it and even recommend to others (most participants seemed to agree with this; about 60 %).

The i–DREAMS system was also found to be rather easy to use. The i–DREAMS' system clarity was also assessed (Fig. 7) and was perceived to be quite high (about 90 %); this was also the case for visual clarity (about 90 %), but less so for auditory clarity (about 50 %). These findings were consistent with the insights provided by the qualitative analysis (4.2.2). In particular, the latter revealed that some improvements could be done by bringing in voice assistance to the warning–system in case of an over–speeding, or in dangerous situations. Some participants found the auditory warnings to be too loud or even confusing. For visual clarity, the qualitative analysis indicated that mostly, warning pictograms were similar to existing ADAS; yet, some comments indicated a confusion with regards to the numbers indicated on the pictograms (such as the ones in Fig. 4 b), whether they referred to time, distance, and were therefore found to be confusing or even distracting. For each of the visual or auditory improvements highlighted, there was a bit of contrast noticed by participants, which suggest a potential lack of familiarity with the system, which could explain this discrepancy, as opposed to a high level of understanding of ADAS in general. One way to get around this would be to have a longer test phase in which participants get further acquainted with the system's different functionalities (with the disadvantage of course of possible higher biases and scenario predictability); better instructing participants on the meaning of such warnings could allow them to better benefit from their usefulness, increasing thereby the system acceptability, as noted in Rossi et al. (2020).

In assessing whether any of the participants' demographics had an impact on their perceptions and attitudes towards ADAS, the i–DREAMS system, or driving distraction, a Chi–square test was conducted with gender as the variable of interest; however, no significant results were obtained to indicate that gender had a significant impact on the observed attitudes. Further, the factor analysis models on perceptions towards ADAS and the i–DREAMS system led to the extraction of two main factors: perceived usefulness, and perceived ease of use –DREAMS system). While some of the factors identified as a result of the previously mentioned factor analysis are slightly different than the ones identified in Rahman et al. (2018), our findings and the methods used are still aligned with the premises of the technology acceptance model. The results from these models are also compatible with the work of several researchers who used factor analyses to understand users' perceptions of emerging transportation systems (Tyrinopoulos & Antoniou, 2008; Efthymiou et al., 2013), or disruptive transport technologies (Al Haddad et al., 2020). In the latter studies, the authors also resorted to factor analyses to reduce initial indicators to fewer factors, each explaining more than 10 % of the total variance (with one exception at most), with a cumulative total variance ranging roughly from an average of 46 % to 55 %.

6.2. Conclusions

The study design, data collection, analysis, and model development, have allowed us to answer the three research questions laid out in the introduction (Section 1). Both perceived usefulness and perceived ease of use were found to directly impact the acceptance of advanced and adaptive in–vehicle warning monitoring systems (in the case of this manuscript, the i–DREAMS system), based on the model results given in Table 7. These findings helped us answer the first research question (**R.Q.1**). In answering the second research question (R.Q.2.), results presented in Table 9 revealed that external variables such as driving's license duration, or in other words driving experience, can significantly impact the perceived ease of use of the i–DREAMS system (adaptive in–vehicle warning monitoring system), and therefore accordingly its acceptance. Finally, to answer the third research question (**R.Q.3.**), namely testing the different components of the classical Technology Acceptance Model (TAM) and seeing whether it can be suitable to represent the acceptance of the i–DREAMS system, the hypotheses drawn in Fig. 2 were tested. To answer the first hypothesis (answered in R.Q.1), an ordered logit model was developed, with "i–DREAMS intention to use" as a dependent variable, and the factors resulting from the factor analysis (Table 6)– i–DREAMS usefulness and ease of use, as independent variables. The model results (Table 7) revealed that both perceived ease of use and perceived usefulness positively and significantly impacted the intention to use, validating thereby the first hypothesis, in line with the study by Rahman et al. (2017) in which TAM was found as suitable to explain the variability in the behavioral intention to use ADAS. This is also in line with previous research (Biassoni et al., 2016; Cho et al., 2017; Viktorová & Šucha, 2018) that highlighted that perceived safety benefits highly impact the system acceptance. To test the second hypothesis (impacts of PEU and of external variables on PU), an ordinal least square model (OLS) –results in Table 8– revealed that the i–DREAMS perceived usefulness was highly impacted by the perceived usefulness of ADAS; this is expected, and also validates the hypothesis partially. On the other hand, there was no indication that the i–DREAMS perceived usefulness highly depended on the i–DREAMS perceived ease of use, which also can be due to the fact that both were newly calculated factors based on the factor analysis results (Table 6). Finally, the third hypothesis was also validated (impact of external variables on PEU), and was answered as part of R.Q.2. In other words, the duration for which a driver has had his or her license significantly impacted his or her perceived ease of use, which could be associated to driver age (the longer the license duration, the older the participant is, in principle), which is compatible with previous research by Xu et al. (2021) that found that driver age was among the influencing factors for ADAS acceptance.

Overall, the three hypotheses were validated (at least partially), answering thereby the final research question (**R.Q.3**) and concluding that the acceptance of the adaptive warning–monitoring system (the i–DREAMS system) could be represented by the technology acceptance model. Based on the observed findings only, a representation of the validated TAM for the current study was drawn, as shown in Fig. 8.

Having answered this paper' research questions, it is important to mention as well that the study does not come without limitations. First, the sample size was limited and could be expanded and improved, mostly to be more representative of the city's driving population's demographics. Moreover, the driving simulator environment, while practical and convenient to test safety–critical scenarios, has its own set of limitations, such as the extent to which it is realistic. Moreover, despite having used advanced sensory equipment including eye–tracking glasses, and wristbands measuring the heart–rate, the questionnaires did not consider the participants' experiences with such equipment, which despite not being explicitly part of the i–DREAMS system, were part of the equipment set–up and could could therefore have impacted the overall system acceptance. Finally, the analysis in this manuscript relied solely on the questionnaire data, and did not consider data from the driving simulator (vehicle driving data). Future research could therefore consider this data, and validate these findings, by comparing both datasets. Still, despite such limitations, the main outcomes highlighted by this study showed that the newly designed warning–monitoring system (the i–DREAMS system) mostly received positive feedback from users; the acceptance of this system, similarly to other technologies was represented by the technology acceptance models. The results highlighted the importance of parameters such as perceived usefulness (benefits) and ease of use and clarity in the intention to use the system. Specific results obtained from this study such as possible improvements of the auditory system, or the importance of above–mentioned factors are crucial in transferring the knowledge to the stakeholders involved in its design, before it is implemented on real road conditions. The study results also highlighted the importance of instructing drivers and making them aware on the functionalities of the ADAS beforehand to increase their acceptability of the system (this was implied from the open–ended questions where a lack of consensus was evident regarding the understanding of specific ADAS symbols), and as demonstrated by Rossi et al. (2020).

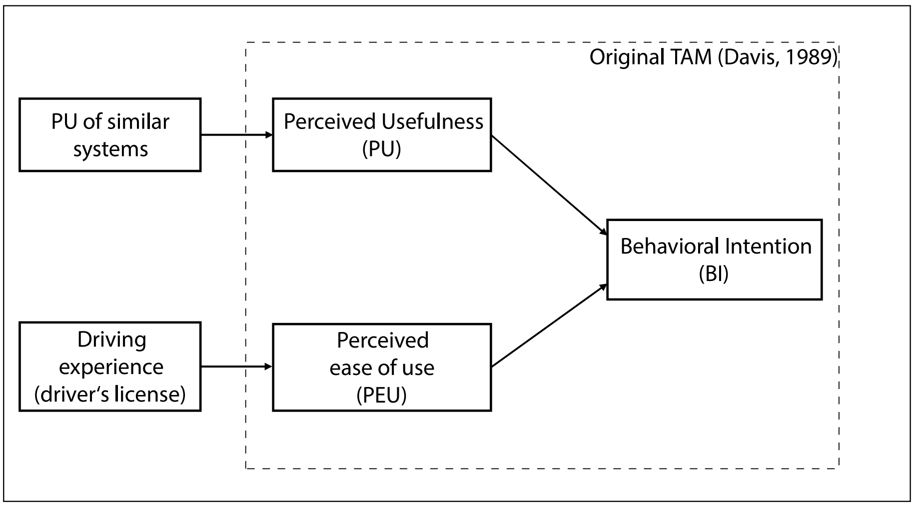

Fig. 8. Validated TAM for the i–DREAMS system (own illustration).

In the i–DREAMS project, and following the simulator experiments, the system was (planned to be) installed in real road conditions for different modes: the findings of this study were therefore used to inform the future road study and proved that driving simulator experiments, combined with a proper set of surveys, can be an efficient and suitable way to test newly developed technologies. Beyond filling the identified research gaps, this manuscript can set the path in establishing TAM as a suitable method for assessing the acceptance of certain ADAS functionalities that are tested in simulator environments first (before being implemented on the road). For our i–DREAMS study, and generally, the findings of this work have implications for vehicle manufacturers and industrial stakeholders, as they use the results of this study to (i) inform and improve the development of the ADAS under investigation (here, the i–DREAMS system), ii) translate the identified factors into real–road requirements to improve the user experience, iii) focus on the identified variable of "driving experience" and map it to suitable information and awareness sessions that improve the understanding of the ADAS functionalities for new users. On a wider scale, the identified findings could also be mapped to providing better insights for policymakers. The acceptance models results highlighted driving experience as a crucial component in relation to the acceptance of ADAS. Improving or influencing driving experience also relates to the above–mentioned discussion on drivers' awareness or knowledge about ADAS. This could be implemented as part of new regulations for updated drivers' license requirements, not only for new licenses, but also for existing ones. In a world of increasing automation, unlocking the full potential of ADAS can only be facilitated by a better understanding of their acceptance, and is the only path towards improved road safety and vision zero.

CRediT authorship contribution statement

Christelle Al Haddad: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mohamed Abouelela:** Writing – review & editing, Visualization, Software, Formal analysis, Data curation. **Kris Brijs:** Writing – review & editing, Methodology, Investigation, Funding acquisition, Conceptualization. **Evelien Polders:** Project administration, Methodology, Investigation, Conceptualization. **Tom Brijs:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Constantinos Antoniou:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. . Additional analysis

Appendix A.1. Statistical data on the attitudinal questions

In the below section, summary statistics on the questionnaires' attitudinal questions (scale 1 to 5) are presented, including mean, standard deviations (std), minimum (min.), maximum (max.), and median. These are presented in Tables A.10 to A.12; the response options for the first two tables range from "strongly disagree" to "strongly agree", whereas for the last table, options range from "very unclear" to "very clear".

Table A.10
Summary statistics of respondents' attitudes towards ADAS (N = 60).

Attitudinal statement	Mean	Std	Min	Median	Max
ADAS are good idea	4.19	0.60	3	4	5
ADAS are clear and understandable	3.78	0.62	3	4	5
ADAS are comfortable	3.52	1.00	1	4	5
The use of ADAS decrease accidents risk	3.86	0.74	1	4	5
ADAS are distracting	2.69	0.80	1	3	4
ADAS are easy to use	3.73	0.69	2	4	5
ADAS help me maintain safe driving	4.05	0.64	3	4	5
ADAS improve driving performance	3.69	0.73	2	4	5
ADAS are reliable	3.54	0.75	1	4	5

(*continued on next page*)

Table A.10 (*continued*)

Attitudinal statement	Mean	Std	Min	Median	Max
ADAS require increased attention	3.00	0.90	1	3	5
ADAS are useful	4.25	0.54	3	4	5

Table A.11
Summary statistics of respondents' attitudes towards the i–DREAMS system (N = 60).

Attitudinal statement	Mean	Std	Min	Median	Max
The i–DREAMS system allows me to multitask	3.07	0.91	1	3	5
The i–DREAMS system distracts me from driving	2.41	0.84	1	2	4
The i–DREAMS system does not negatively affect my driving	3.88	0.91	2	4	5
The i–DREAMS system helps me maintain safe driving	3.75	0.63	2	4	5
The i–DREAMS system helps me reach my destination safely	3.39	0.64	2	3	5
The i–DREAMS system I can depend on it	3.24	0.90	1	3	5
I do not understand the i–DREAMS system	1.81	0.88	1	2	5
I know how to use the i–DREAMS system	4.08	0.73	2	4	5
The i–DREAMS system improves my driving performance	3.20	0.92	1	3	5
The i–DREAMS system is a good idea	3.86	0.66	2	4	5
The i–DREAMS system is annoying	2.14	0.78	1	2	4
The i–DREAMS system is easy to understand	4.19	0.54	3	4	5
The i–DREAMS system makes driving interesting	2.92	0.88	1	3	5
The i–DREAMS system makes me a safer driver	3.47	0.73	2	4	5
The i–DREAMS system makes me more aware of my surroundings	3.53	0.88	2	4	5
People would encourage me to use the i–DREAMS system	3.37	0.72	2	3	5
Proud to show the i–DREAMS system to people	3.32	0.84	1	4	5
The i–DREAMS system requires increased attention	3.02	0.92	1	3	5
I would continue to use the i–DREAMS system	3.53	0.82	1	4	5
I would recommend the i–DREAMS system to others	3.61	0.79	2	4	5

Table A.12
Summary statistics of respondents' attitudes towards the i–DREAMS system clarity (N = 60).

Agreement statement	Mean	Std	Min	Median	Max
System visual clarity	3.50	1.29	2	3.50	5
System sound clarity	3.50	1.29	2	3.50	5
System overall clarity	3.25	1.71	1	3.50	5

Appendix A.2. Additional plots

In the following section, additional plots are presented for the various attitudinal statements. It is important to note that for most statements, there were no significant differences in the results between males and females, as noted based on the results of the Chi–square of independence between the variables and gender. Only for ADAS availability (Figure A.9), a significant difference (up to the 95 % level of confidence) was observed between males and females in the presence of adaptive cruise control and of high speed alert.

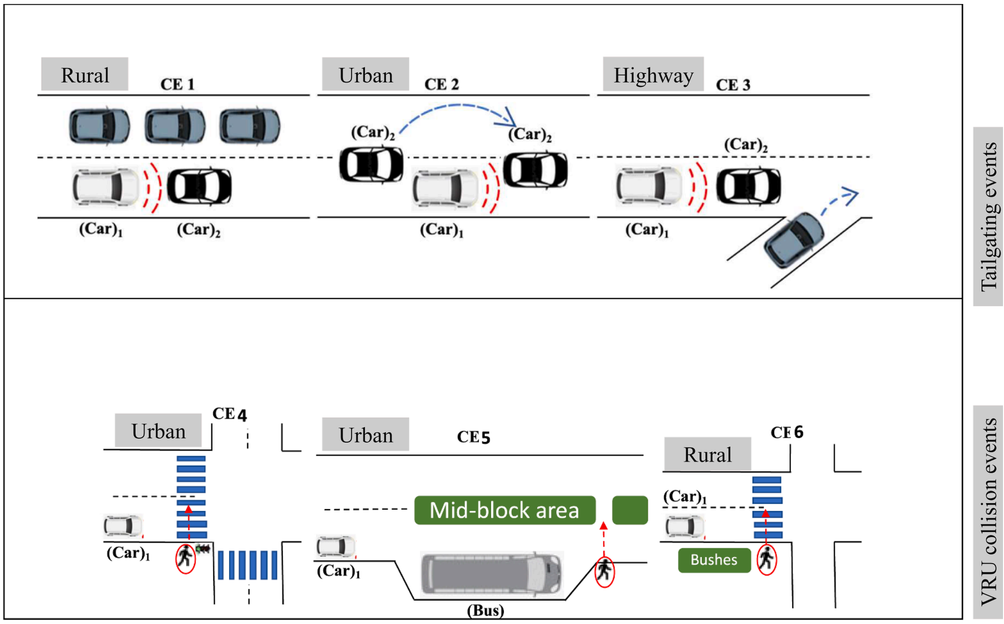

Fig. A.9. ADAS availability (N = 60)

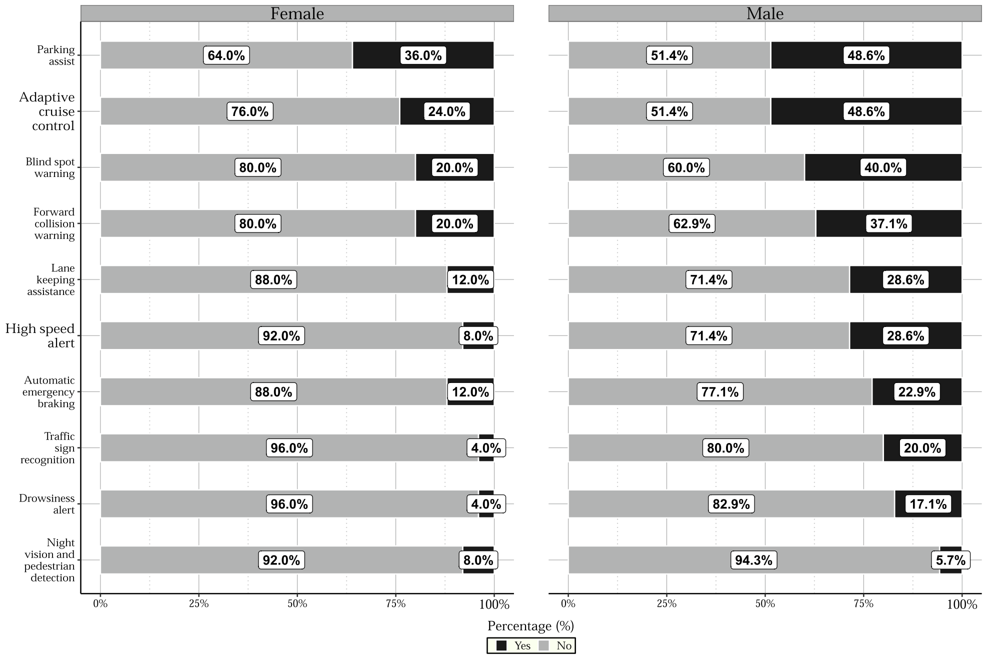

Fig. A.10. ADAS frequency of use (N = 60)

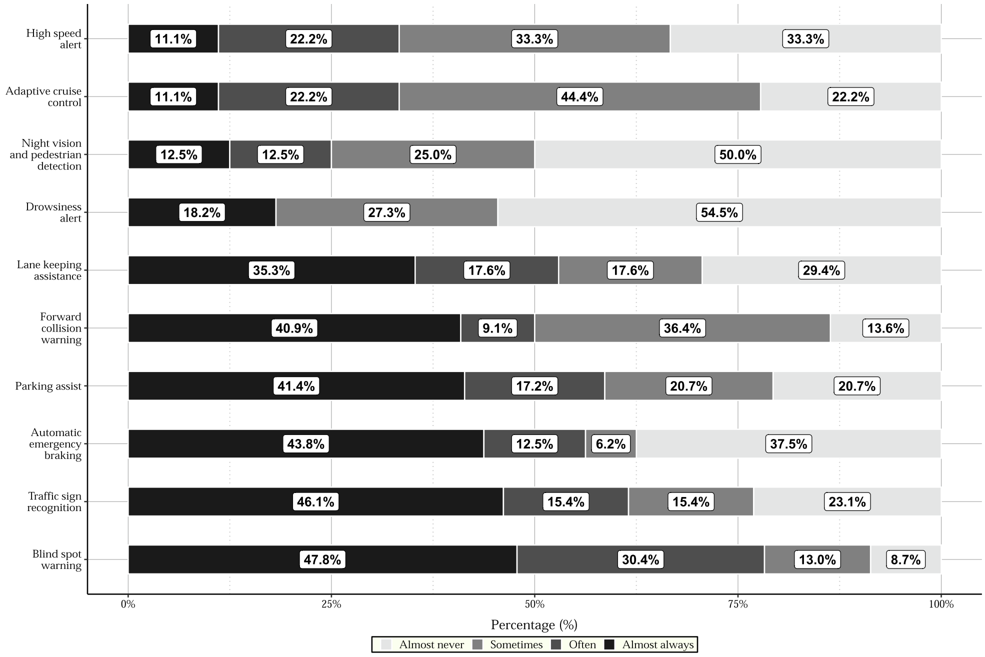

Fig. A.11. Distraction engagement when driving (N = 60)

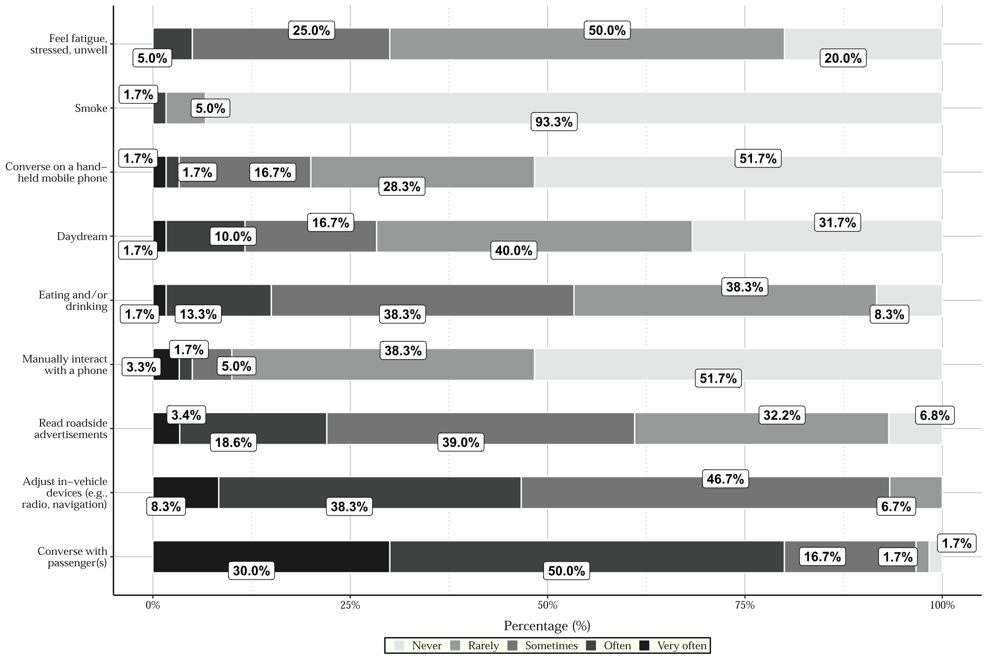

Fig. A.12. You think it is okay to drive and [] (N = 60)

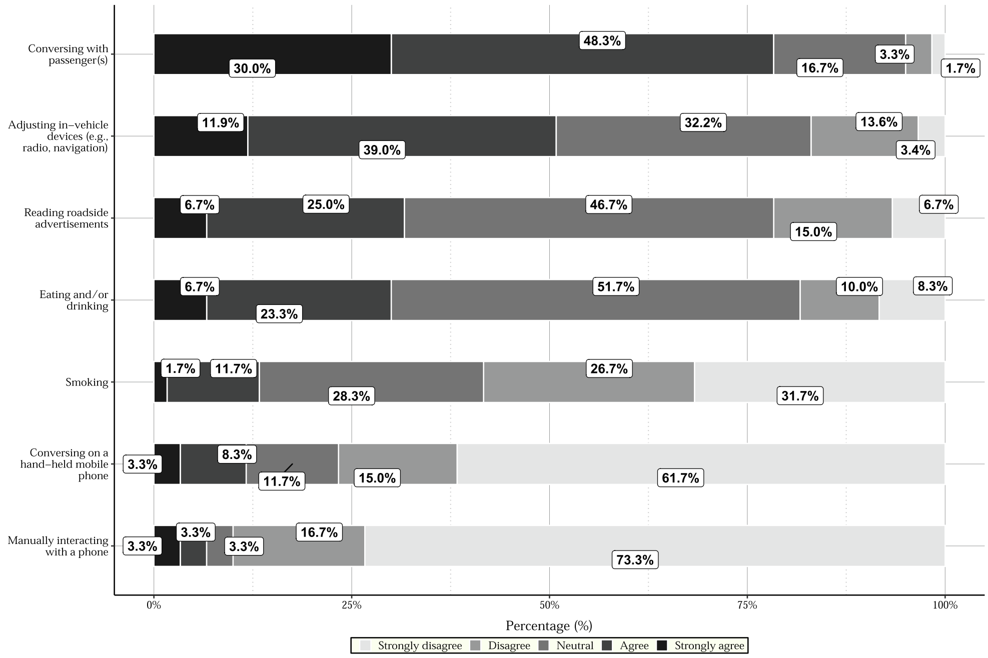

Fig. A.13. You believe you can drive well while [] (N = 60)

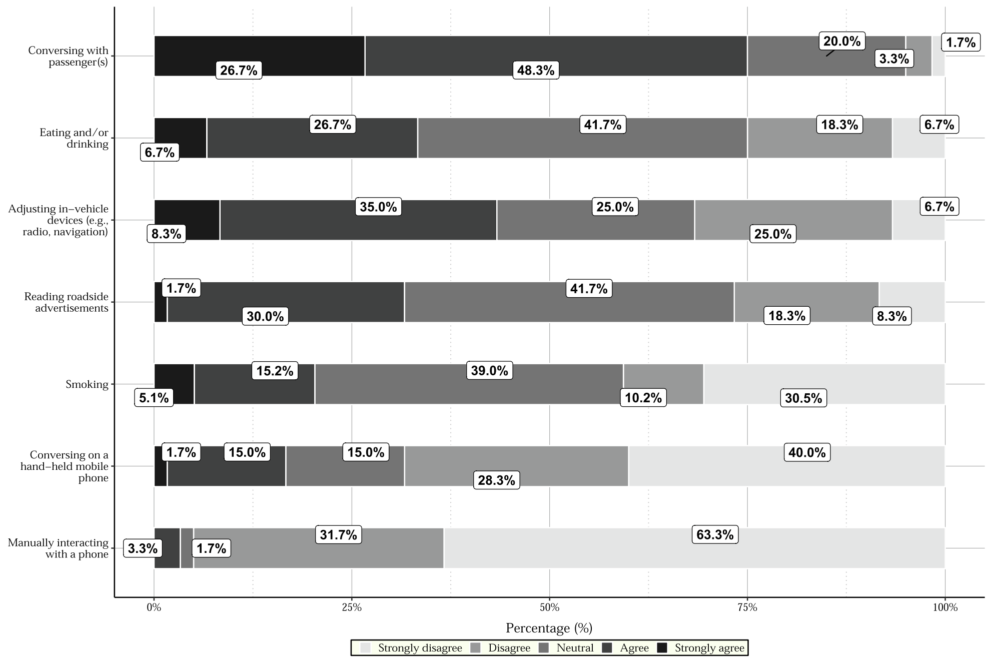

Fig. A.14. While driving, you find it distracting to [] (N = 60)

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