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RESEARCH ARTICLE

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Smarter cycling, safer cycling? Acceptance of advanced cyclist assistance systems in 19 European countries

Nora Studer[a], Dorothea Schaffner[a], Steve O'Hern[b], Trond Nordfjærn[c], Francisco Alonso[d], Predrag Brlek[e], Mile Cavar[f], Katarzyna Gdowska[g], Javier Gene-Morales[d], Jozef Gnap[h], Giuseppe Guido[i], Milad Mehdizadeh[b], Mette Møller[j], Dimitrios Nalmpantis[k], Mihai R. Niță[l], Ksenia Shubenkova[m], Sergio Traficante[d], Zermena Vazne[n], Katrina Volgemute[n] and Sergio A. Useche[d]

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ABSTRACT

As cycling grows in popularity as a sustainable transport mode in Europe, cyclist safety has become a priority. Advanced Cyclist Assistance Systems (ACAS), inspired by Advanced Driver Assistance Systems (ADAS), offer potential safety improvements but remain underexplored. This study examines ACAS acceptance among 5,991 cyclists from 19 European countries, focusing on public perceptions and adoption drivers. Participants evaluated various ACAS types—crash prevention, visibility enhancement, environmental monitoring, and post-crash assistance—based on safety, usability, and reliability. Acceptance varied across countries, with higher rates in areas with strong cycling infrastructure. Safety and reliability were universally valued, though gender differences emerged: women prioritised safety and visibility, while men favoured usability and added features. The findings highlight the importance of infrastructure, reliable technology, and awareness efforts to promote adoption. Policymakers and developers can use these insights to tailor ACAS innovations, ultimately enhancing cycling safety and supporting the broader development of smart, cyclist-focused technologies.

PRACTITIONER SUMMARY: The study investigates the acceptance of Advanced Cycling Assistance Systems (ACAS) by European cyclists. Safety features and system reliability were the most valued attributes across all countries. The authors conclude that these systems have a larger chance of adoption in the market, contributing to road safety for cyclists.

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KEYWORDS
Advanced cyclist assistance systems; smart bicycles; riding safety; technology acceptance; emerging cycling phenomena

1. Introduction

Advanced Driver Assistance Systems (ADAS) continue to gain traction in the automotive industry. ADAS enhance human-machine interaction and improve vehicle and road safety by assisting drivers using sensors, cameras, and automated technologies to detect obstacles and alert drivers to potential hazards (Lijarcio et al. 2019). They comprise a set of in-vehicle technologies designed to support drivers through functions such as collision warnings, lane-keeping assistance, and automated braking. At a practical level, some studies have consistently supported that one of the added values of relying on sensors, cameras, and real-time processing is that these systems reduce human error and have been associated with notable improvements in crash prevention and overall road safety (Bosurgi et al. 2023; Greenwood, Lenneman, and Baldwin 2022; Lijarcio et al. 2019).

Their widespread implementation in cars and motorcycles has provided valuable evidence of how automation can enhance user safety, offering a relevant precedent for transferring similar concepts to the cycling domain. Specifically, previous research on ADAS has extensively studied safety impacts (Gulino et al. 2025; Lee et al. 2021) and acceptance (Hansen

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et al. 2025; Kaye et al. 2024) of these systems both in the context of driving and motorcycling.

The integration of similar technologies in bicycles, that is Advanced Cyclist Assistance Systems (ACAS), is less advanced despite their potential to improve cycling safety and cycling experience (Skoczyński 2021; Wang et al. 2024). Furthermore, data collected from ACAS can be used for cycling research to enable more detailed analysis of critical infrastructure and risk factors, thereby contributing to improved cycling safety (Gadsby and Watkins 2020).

Recent studies suggest that ACAS will undergo significant advancements in the coming years due to the rapid progress in technology, the proliferation of e-bikes whose battery provides a built-in power source, and an increasing public concern for cycling safety (Berge, De Winter, and Hagenzieker 2023; Kiefer and Behrendt 2016).

Cycling safety has become an increasing concern for policymakers, urban planners, and public health professionals, as cycling gains popularity due to its well-established health and environmental benefits over motorised means (International Transport Forum 2018; Useche, Llamazares, and Marin 2024). Notwithstanding these benefits, the proportion of cycling crashes resulting in death or serious injury rose from 7% to 9% between 2010 and 2019, whereas overall road fatalities and serious injuries in the European Union dropped by 23% during the same period (European Commission 2021). Previous studies have suggested that cycling safety figures are influenced by an interaction of infrastructure, human factors, and vehicle design (Hakkert and Gitelman 2014; Reynolds et al. 2009; Schepers et al. 2014). While each of these components play a relevant role in determining the overall safety of cyclists on the road, the present study focuses on vehicle-related technologies, such as ACAS, and their potential to contribute to cycling safety.

However, similar to other technological developments, achieving the potential safety benefits of ACAS depends on the willingness of people to accept and use these innovations (Davis 1989). A recent study has shown the importance of identifying the relevant psychological factors that influence cyclists' willingness to use bicycles with ACAS (Kapousizis et al. 2024). Results have shown that the intention to use bicycles fitted with ACAS is influenced by perceiving them as useful, enjoyable, and contributing to cycling safety. Further findings indicate that user acceptance varies across different ACAS functionalities (Wang et al. 2024).

Table 1. ACAS group taxonomy according to their primary functionality or contribution to the riding experience.

ACAS group	Label	Description
Group 1	Environmental monitoring	Systems that monitor the cyclist's surroundings to detect other road users posing a potential threat.
Group 2	Rider visibility	Systems designed to enhance the cyclist's visibility to other road users.
Group 3	Real-time information	Systems providing current information about the trip, such as cycling speed or way-finding.
Group 4	Crash-prevention assistance	Systems that assist cyclists in avoiding falls or collisions during critical manoeuvres (e.g. braking, turning).
Group 5	Post-crash appliances	Systems that assist cyclists after a crash, such as storing crash data or sending emergency calls.

2. Background

2.1. Definition and categories of ACAS

Within the cycling industry, different terms for ACAS exist. While the term ACAS has recently become common (Useche, Alonso, and Oviedo-Trespalacios 2024; Wang et al. 2024), others generally refer to bicycle technologies (Kapousizis, Ulak, and Geurs 2023; Kapousizis, Ulak, Geurs, et al. 2023), to instrumented bikes (Gadsby and Watkins 2020), or define a wider approach labelled 'smart cycling' (Oliveira et al. 2021). To maintain consistency in terminology and to emphasise the similarity to ADAS, we will subsequently use the term ACAS. At a taxonomical level, these systems can be categorised into five different core types based on their functionalities (Useche, Alonso, and Oviedo-Trespalacios 2024), as shown in Table 1.

2.2. User acceptance

Several studies agree that understanding users' attitudes towards new technologies, such as ACAS, is needed to maximise their impact, as their potential can only be realised when individuals accept and use these technologies (Davis 1989; Venkatesh, Thong, and Xu 2012). The extended version of the Unified Theory of Acceptance and Use of Technology (UTAUT2) is a well-established theoretical framework to investigate acceptance of new technologies (Venkatesh, Thong, and Xu 2012). It combines various models relevant for technology acceptance such as the Technology Acceptance Model and the Theory of Planned Behaviour (Venkatesh et al. 2003, Venkatesh, Thong, and Xu 2012). UTAUT2 was specifically developed to investigate technologies in a consumer context and its application has been demonstrated in studies about the acceptance of new bicycle sharing technologies (Jahanshahi, Tabibi, and Van Wee 2020), secondary task engagement (O'Hern et al. 2025), or the acceptance of e-bikes with ACAS (Kapousizis et al. 2024).

UTAUT2 describes how several psychological factors influence use intention (Venkatesh, Thong, and Xu 2012). Furthermore, the sociodemographic characteristics of age and gender, as well as previous experience may moderate the effect of these factors. Use intention then influences actual behaviour, that is, the use of a novel technology. Since ACAS present new technologies that have not seen widespread commercial use, acceptance is here defined as the intention to use ACAS. Furthermore, willingness to pay is used to measure acceptance as cyclists would need to purchase ACAS themselves, unlike ADAS for cars which are often subject to regulatory requirements.

In previous studies about the acceptance of new bicycle technologies, UTAUT2 has been adapted to fit the specific context (Jahanshahi, Tabibi, and Van Wee 2020; Kapousizis et al. 2024). In the present study, we utilised the UTAUT2 as the underlying theoretical framework, selecting the three most appropriate factors for the context of ACAS and adjusting the terminology to be context-specific:

- Performance expectancy refers to the utilitarian value of a technology; applied to ACAS, this refers to the perceived *safety* contribution as well as its additional and unique contribution compared to existing solutions.
- Effort expectancy describes the *ease of use* of a new technology and was adapted to the expected ease of use of ACAS.
- Facilitating conditions concern the perceived support for using a technology, which also refers to reliability or *trust* in its functioning.
- Additionally, the factor *novelty* was added as the perceived innovativeness of a new technology can influence acceptance, either positively by offering enhanced features or negatively by requiring a more demanding adaptation process (Mugge and Dahl 2013).

2.3. Study aims and hypotheses

Despite the growing relevance of ACAS for cycling safety, there is limited research on the acceptance of different ACAS functionalities. Furthermore, it remains unclear which factors influence cyclists' acceptance across different ACAS. To close this research gap, the present study aims to apply an adapted version of the UTAUT2 to investigate the use intention and willingness to pay for five categories of ACAS. Consequently, the present study seeks to answer the following research questions, following their respective literature-based hypotheses:

2.3.1. Research question 1

What is the level of acceptance for five distinct categories of ACAS (environmental monitoring, rider visibility, real-time information, crash-prevention assistance, post-crash appliances) among cyclists?

2.3.2. Hypothesis 1 (H1)

Drawing on existing literature on Advanced Cyclist Assistance Systems (ACAS) and their functionalities (e.g. Skoczyński 2021; Wang et al. 2024), it is hypothesised that cyclists will demonstrate higher acceptance for ACAS features focused on enhancing rider visibility and providing crash-prevention assistance. These features are expected to be valued more highly than systems related to real-time information or post-crash assistance, as they directly address perceived risks and enhance immediate cycling safety.

2.3.3. Research question 2

To what extent do sociodemographic characteristics, cycling use, and psychological factors (perceived safety, ease of use, trust, and novelty) determine acceptance of ACAS, that is, use intention and willingness to pay?

2.3.4. Hypothesis 2 (H2)

Building on theoretical frameworks regarding technology acceptance and user behaviour (e.g. Hauk, Hüffmeier, and Krumm 2018; Son, Park, and Park 2015), it is hypothesised that sociodemographic characteristics (such as age and gender), cycling use (including frequency of cycling), and psychological factors (including perceived safety, ease of use, trust, and novelty) will significantly predict cyclists' acceptance of ACAS. Specifically, younger cyclists, more frequent cyclists, and those exhibiting higher trust in technology are expected to show greater willingness to adopt and pay for ACAS.

3. Methodology

3.1. Data collection

Data were collected via online survey as part of the project Bike Barometer II which investigates cycling behaviour, trends, and technologies related to cycling safety. Eligibility criteria for participating included being able to cycle and having some experience using the road system. Data collection was conducted between the European autumn 2023 and summer 2024. Researchers from participating countries independently translated the survey into the respective languages and carried out data collection. They used a variety of sampling strategies including distribution via social media, institutional mailing lists, or online panels of market research companies. All participants have provided written informed consent.

3.2. Ethics

The procedures for this study were reviewed and approved by the Research Ethics Committee at the Research Institute on Traffic and Road Safety (IRB approval number HE0001291022), ensuring full compliance with the principles outlined in the Declaration of Helsinki and the General Data Protection Regulation (GDPR). The research protocol was deemed to pose very low risk to participants, as only basic demographic information, cycling habits, and questionnaire-based self-reported data were collected, with no sensitive personal data involved.

Additionally, to preserve anonymity, all unnecessary details, such as participants' names, addresses, or contact numbers, were not recorded. Also, as standardised for its European framework, this study specifically focused on cyclists aged 18 and older (no minors were surveyed), used an informed consent form to explain participants 'rights and duties' – especially the voluntary and merely scientific character of the participation, and warranted participants' confidentiality throughout the data collection process.

3.3. Measures

Participants evaluated ten ACAS, with two ACAS each from five different categories (see Table 2). ACAS were described in one sentence and presented with a visualisation. Each ACAS was assessed with six items, rated on a 5-point Likert scale ranging from (1) *Very poor* to (5) *Excellent*. Four items measured the factors safety, trust, novelty, and ease of use; two items measured acceptance, that is, willingness to pay and use intention. Cycling performance, a self-assessment of cycling skills, was measured with one item on a 10-point Likert scale from (1) *Very bad* to (10) *Perfect*.

3.4. Statistical analysis

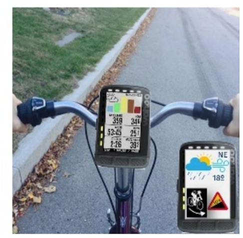
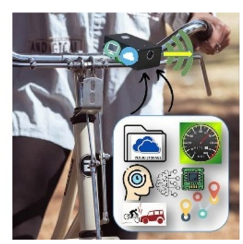
To assess differences in the acceptance ratings of ACAS categories, repeated measures ANOVAs were conducted using a multilevel model. ANOVA effect sizes were estimated using eta-squared (η^2). Post-hoc comparisons were performed using Tukey's HSD, and effect sizes were reported with Cohen's *d* (Cohen 1992). In addition, a set of analyses of covariance (ANCOVA) was conducted to examine potential cross-country differences in willingness to pay and intention to use ACAS. These models included cyclists' age as a covariate to account for possible age-related influences. Regarding reliability and consistency indicators, Alpha coefficients were calculated to assess the internal consistency of the study scales, with a pre-defined threshold of > 0.700 considered acceptable for inclusion in further analyses, as suggested in specialised literature (Stensen and Lydersen 2022; Tavakol and Dennick 2011).

Ordinal logistic regression models were employed to examine the extent to which sociodemographic characteristics, cycling use, and psychological factors (safety, trust, ease of use, novelty) predicted willingness to pay and use intention regarding ACAS. For each ACAS category, hierarchical regression models were estimated. Model 1 included the sociodemographic variables age, gender, and education. Model 2 added cycling hours per week and cycling performance. Model 3 incorporated psychological factors: safety, trust, novelty, and ease of use. Each model was first run with all predictors and subsequently re-estimated using only those predictors found to be statistically significant.

An initial Exploratory Factor Analysis (EFA) of the ACAS scale was conducted using Maximum Likelihood (ML) estimation with Oblimin rotation. ML was chosen for its ability to yield unbiased parameter estimates and standard errors, even under conditions of multivariate non-normality (Costello and Osborne 2005). The EFA, conducted on all 10 items of the questionnaire, supported a five-factor solution, with all items loading above .500. This theoretically coherent structure was subsequently tested using Confirmatory Factor Analysis (CFA) to validate its dimensionality, following psychometric standards in traffic psychology (Brown 2015; Ledesma et al. 2021).

The model's Goodness of Fit was evaluated using several ordinal and incremental (Brown 2015; Ledesma et al. 2021). Specifically, Normed Fit Index (NFI), Relative Fit Index (RFI), Confirmatory Fit Index (CFI), Tucker-Lewis Index (TLI), and Incremental Fit Index

Table 2. Overview of the ACAS evaluated in the present study.

Category	ACAS	Visualisation	
(1) Environmental monitoring	(1) Proximity radar (2) Rear-view display		
(2) Rider visibility	(3) Turn signalling device (4) Automated lighting system		
(3) Real-time information	(5) Built-in navigation display (6) On-board control centre		
(4) Crash-prevention assistance	(7) Balance/turning assistance system (8) Automated/enhanced braking system		
(5) Post-crash appliances	(9) Emergency notification system (10) Pre-crash data storage ('black box')		

(IFI), alongside the Root Mean Square Error of Approximation (RMSEA). The fit thresholds were based on established guidelines in the literature (Marsh, Hau, and Wen 2004), with values above .900 for the incremental indices and RMSEAs below .080 indicating a suitable model fit, in conjunction with the theoretical coherence of the model paths.

Additionally, following expert literature recommendations, a Monte Carlo parametric bootstrapping procedure was applied, generating 2,000 subsamples to assess model stability and correct for bias through iterative testing (Andrews and Buchinsky 2000; Efron and Tibshirani 1994). This approach enabled the correction of standardised coefficients under optimal reliability assumptions and the estimation of 95% confidence intervals, thereby minimising the risk of Type I or Type II statistical errors (Efron and Tibshirani 1991; Gilleland 2020).

The statistical analyses reported in this article were performed using the R software environment, and IBM; SPSS AMOS (version 29.0) for structural and confirmatory analyses.

4. Results

4.1. Descriptives

4.1.1. Sample characteristics

The sample used in this study consisted of 5,991 cyclists from 19 European countries. Participants included 2,727 (45.5%) women, 3,214 (53.6%) men, and 50 people (< 1%) of diverse gender. The mean age of the sample was 35.3 years (*SD* = 15.6), with a range from 16 to 80 years. The country and gender distribution of the sample are presented in detail in Table 3.

Twenty-one participants (<1%) had an educational level of primary school or lower, 1,253 (22.1%) had an educational level of secondary school, 750 (13.2%) had technical-intermediate training, 2,935 participants (51.7%) had a university degree, 713 (12.6%) were postgraduates, and 319 participants did not indicate their level of education. On average, participants cycled 4.5 hours per week (*SD* = 4.6) and had a cycling trip length of 40.6 minutes (*SD* = 39.1). Self-assessed cycling performance had a mean of 7.6 (*SD* = 1.9).

As a first step, we conducted an analysis of covariance to explore whether willingness to pay and intention to use ACAS differed across countries (see Table 3 for descriptives), while statistically controlling for cyclists' age. The results indicated clear national differences in willingness to pay, $F(17, 5681) = 44.34$, $p < .001$, whereas age did not exert a significant effect, $F(1, 5681) = 1.35$, $p = .245$, suggesting that the variability observed was mainly attributable to differences between countries. A parallel analysis on intention to use ACAS also revealed significant cross-country variation, $F(17, 5681) = 48.28$, $p < .001$, with no significant effect of age, $F(1, 5681) = 2.53$, $p = .112$, thus confirming that these national differences persisted independently of cyclists' age.

4.1.2. Acceptance ratings of ACAS

4.1.2.1. Safety. Figure 1 shows the average safety ratings for the ten different ACAS. While the mean is displayed as a line, the box indicates one standard deviation above and below the mean. Highest ratings were given to both ACAS from the categories environmental monitoring (proximity radar: *m* = 3.71; rear-view display: *m* = 3.75) and rider visibility (turn signalling device: *m* = 3.99; automated lighting system: *m* = 4.05) as well as the automated/enhanced braking system (*m* = 3.83) from the ACAS crash-prevention assistance and the emergency notification system (*m* = 3.80) from the post-crash appliances.

4.1.2.2. Trust. Figure 2 displays the average trust ratings for the ten different ACAS. The highest trust was shown in one ACAS for environmental monitoring (rear-view display: *m* = 3.70), both ACAS for rider visibility (turn signalling device: *m* = 3.84; automated lighting system: *m* = 3.80) as well as one ACAS for real-time information (built-in navigation display: *m* = 3.60).

4.1.2.3. Novelty. Figure 3 shows the average ratings for novelty of the ten different ACAS. Considered as the most novel was one ACAS for environmental monitoring (proximity radar: *m* = 3.76). However, most ACAS received similar moderate ratings, such as the

Table 3. Descriptives of the study sample by country, gender ratio, WTP and intention.

			Gender	WTP[b]	Intention[c]
Country	Frequency	Percent	M:F:O ratio[a]	M (SD)	M (SD)
Bosnia and Herzegovina	169	2.8	1:0.54:0.0	3.13(.81)	3.40(.80)
Croatia	148	2.5	1:0.99:0.01	3.05(.85)	3.30(.87)
Finland	281	4.6	1:0.74:0.07	1.94(.75)	2.53(.87)
France	139	2.3	1:4.48:0.08	2.38(.74)	2.92(.77)
Greece	833	13.9	1:0.62:0.01	3.03(.91)	3.44(.86)
Italy	156	2.6	1:0.41:0.01	2.88(.85)	3.34(.80)
Latvia	299	5	1:0.72:0.01	2.50(.78)	2.71(.74)
Norway	311	5.2	1:1.88:0.0	2.35(.70)	2.68(.75)
Romania	297	5	1:0.32:0.01	2.96(1.04)	3.27(.99)
Russia	404	6.7	1:0.58:0.0	2.94(1.04)	3.13(1.08)
Serbia	294	4.9	1:0.75:0.01	3.13(.91)	3.43(.91)
Slovakia	225	3.8	1:0.74:0.02	2.78(.81)	3.08(.82)
Spain	560	9.3	1:1.49:0.01	2.90(.80)	3.24(.88)
Sweden	284	4.7	1:1.51:0.06	2.00(.80)	2.41(.83)
Switzerland	535	8.9	1:1.48:0.0	2.59(.97)	2.88(.95)
Ukraine	430	7.2	1:0.8:0.02	2.88(.71)	3.65(.68)
Germany	507	8.5	1:1.47:0.03	2.48(.95)	2.79(.92)
Poland	76	1.3	1:0.85:0.0	2.91(.97)	3.00(.82)
Portugal	43	.7	1:0.3:0.0	2.36(.92)	3.11(1.01)
Total	5991	100	1:0.92:0.02	2.74(.93)	3.11(.94)

[a]Gender ratio (Male:Female:Other).
[b]Willingness to pay [0–4] scale.
[c]Intention to use [0–4] scale.

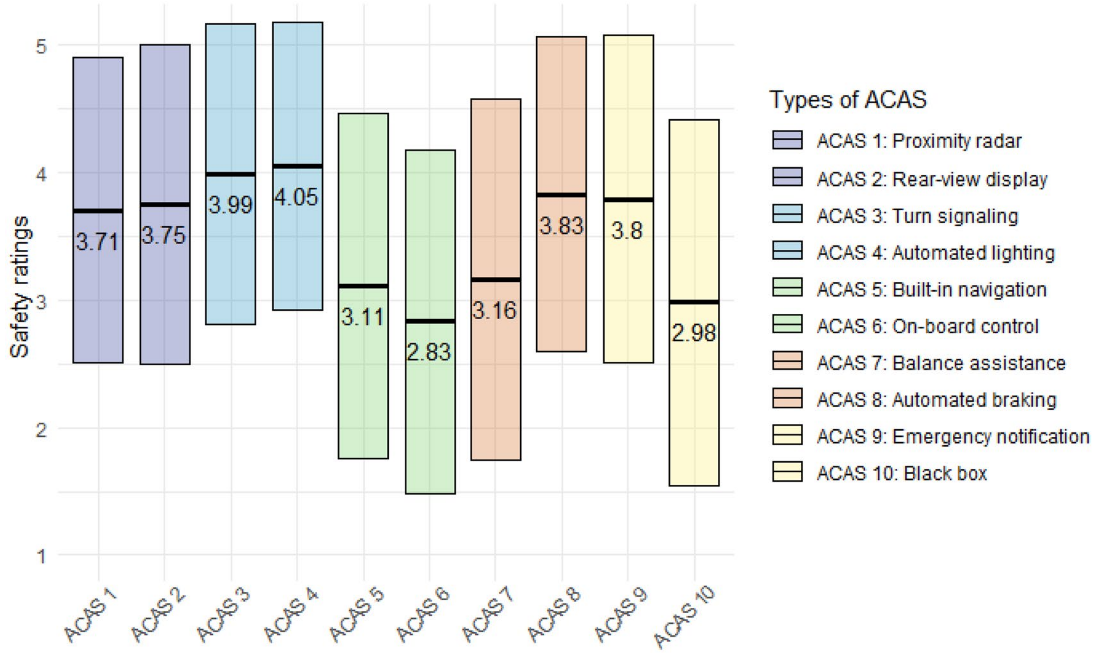


Figure 1. Acceptance ratings for safety of ACAS.

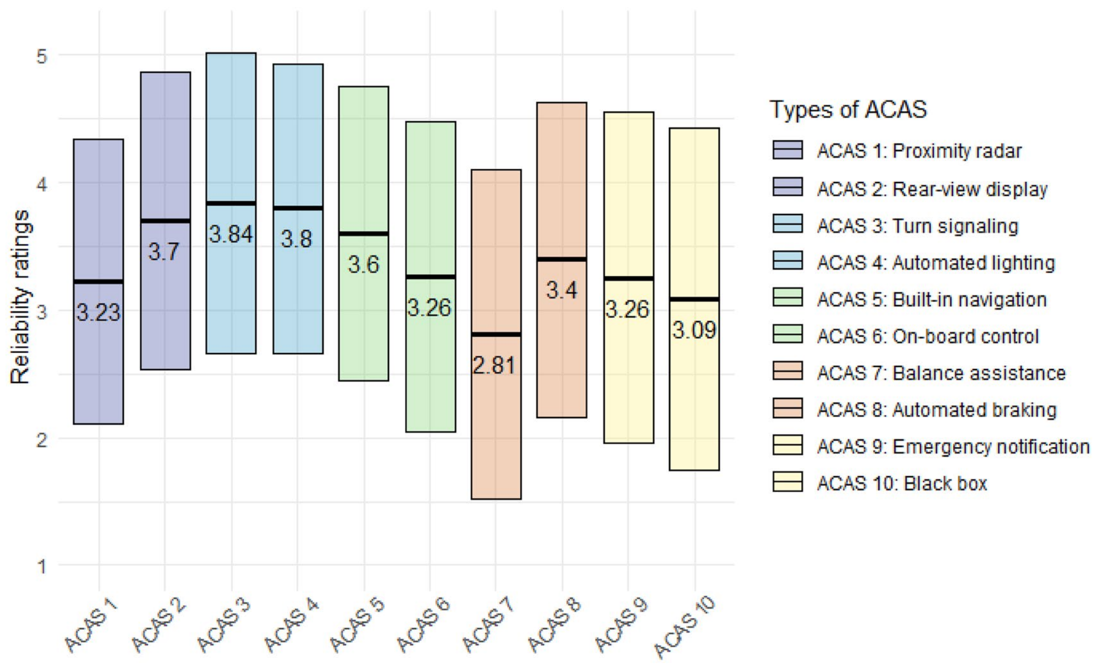


Figure 2. Acceptance ratings for trust in ACAS.

other ACAS for environmental monitoring (rear-view display: $m = 3.62$), one ACAS for rider visibility (automated lighting system: $m = 3.56$), both ACAS for crash-prevention assistance (balance/turning assistance system: $m = 3.56$, automated/enhanced braking system: $m = 3.60$), and one post-crash appliance (emergency notification system $m = 3.55$).

4.1.2.4. Ease of use. Figure 4 shows the average ratings for ease of use of the ten different ACAS. ACAS for rider visibility (turn signalling device: $m = 3.90$; automated lighting system: $m = 4.08$) received the highest ratings. Moderate ratings were given to both ACAS for environmental monitoring (proximity radar: $m = 3.52$, rear-view display: $m = 3.68$), one ACAS for real-time information (built-in navigation display: $m = 3.52$), one ACAS for crash-prevention assistance (automated/enhanced braking system: $m = 3.53$), as well as one post-crash appliance (emergency notification system: $m = 3.54$).

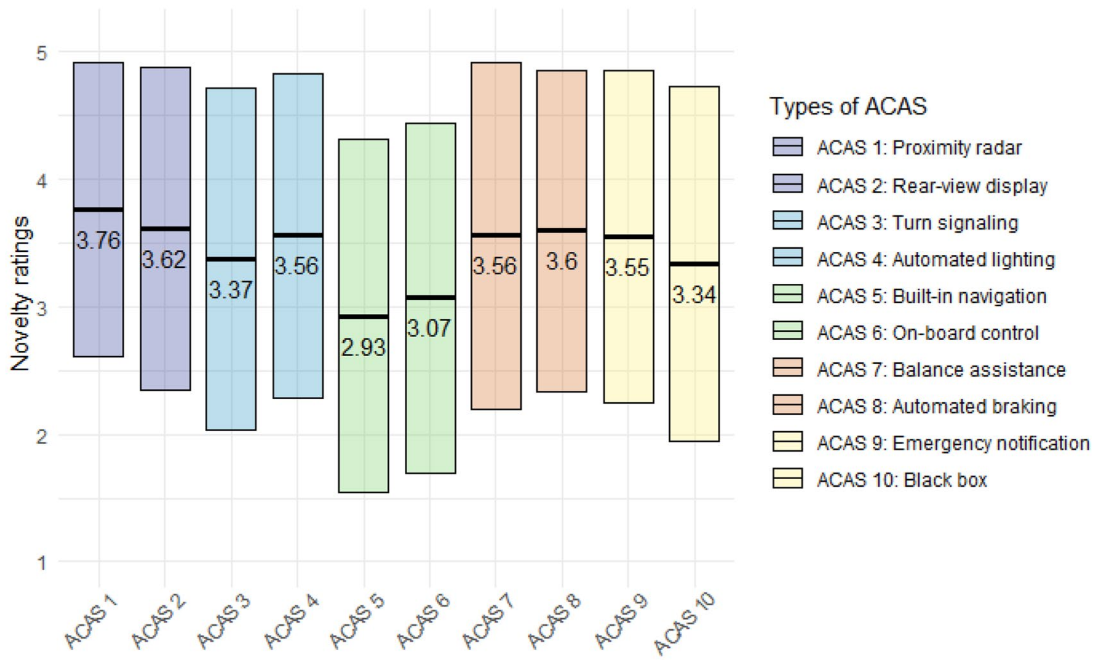


Figure 3. Acceptance ratings for novelty of ACAS.

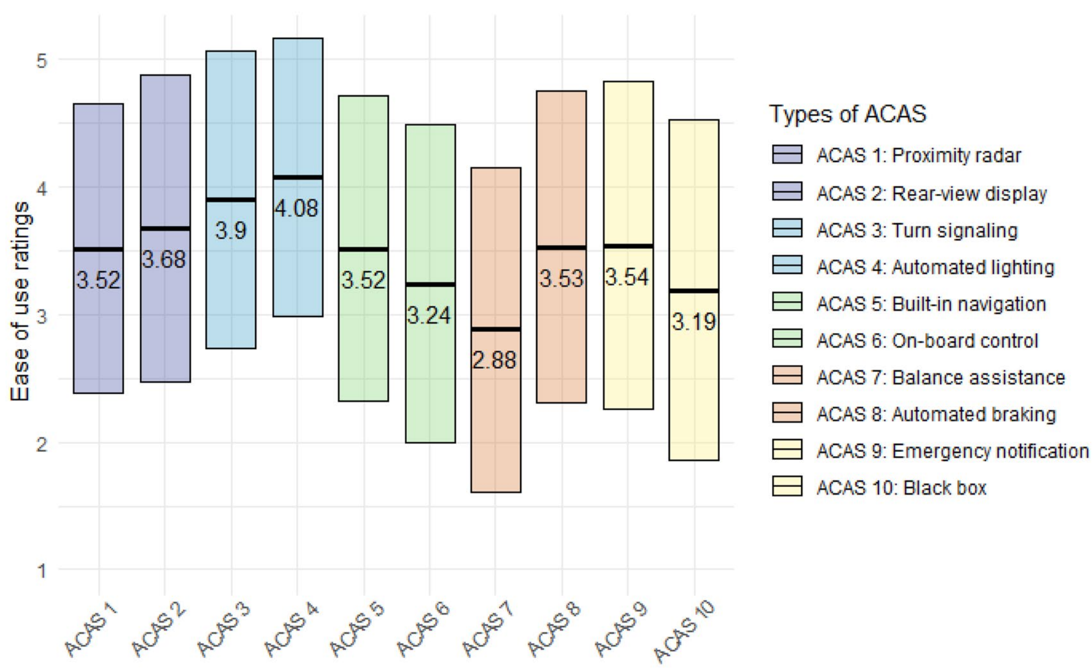


Figure 4. Acceptance ratings for ease of use of ACAS.

4.1.2.5. Willingness to pay. Figure 5 shows the average ratings for willingness to pay for the ten different ACAS. The highest ratings received both ACAS for rider visibility (turn signalling device: $m = 2.98$; automated lighting system: $m = 3.13$), as well as one ACAS each of the other categories: environmental monitoring (rear-view display: $m = 2.79$), real-time information (built-in navigation display: $m = 2.81$), crash-prevention assistance (automated/enhanced braking system: $m = 2.85$), and post-crash appliances (emergency notification system: $m = 2.78$).

4.1.2.6. Use intention. Figure 6 shows the average ratings for the intention to use the different ACAS. Highest use intention received ACAS for rider visibility (turn signalling device: $m = 3.62$; automated

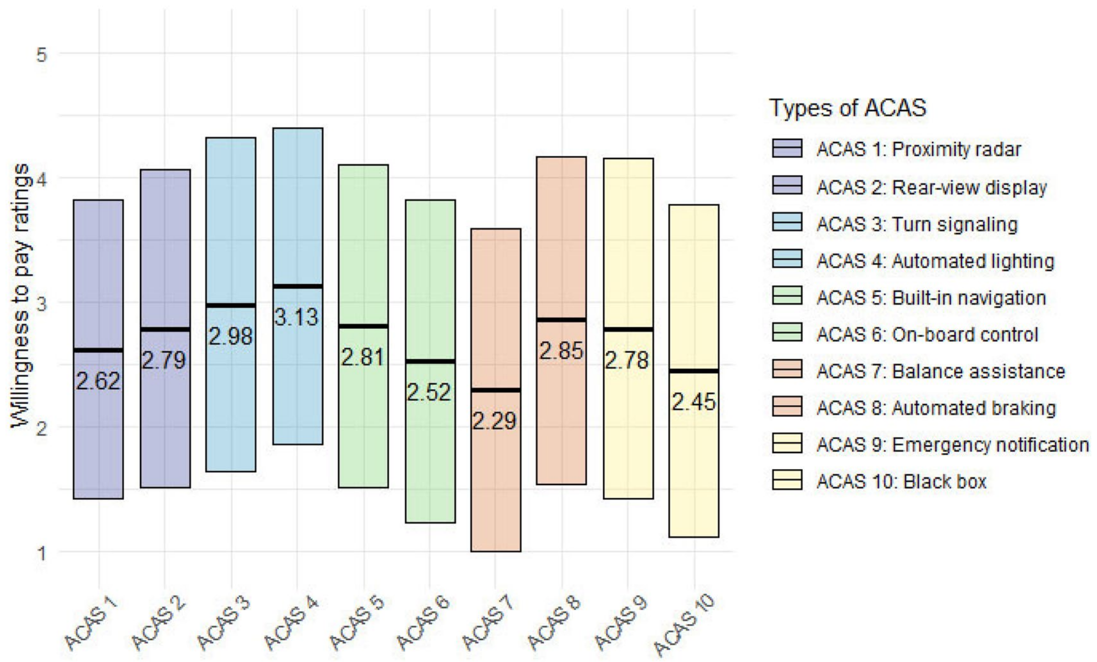


Figure 5. Ratings for willingness to pay for ACAS.

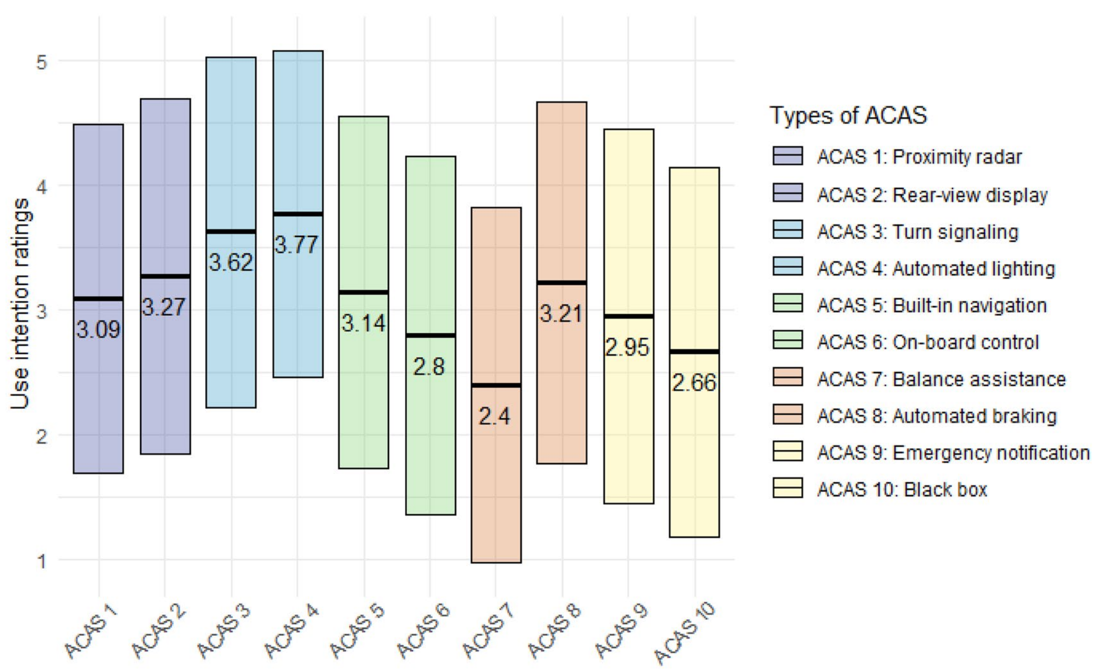


Figure 6. Ratings for use intention for ACAS.

lighting system: $m = 3.77$). Moderate ratings were given to both ACAS for environmental monitoring (proximity radar: $m = 3.09$, rear-view display: $m = 3.27$), one ACAS for real-time information (built-in navigation display: $m = 3.14$), and one ACAS for crash-prevention assistance (automated/enhanced braking system: $m = 3.21$).

4.2. Confirmatory factor analysis

The SEM-based Confirmatory Factor Analysis (CFA) showed a good overall fit to the data. Fit indices were consistently above the recommended thresholds, with NFI = .973, RFI = .952, CFI = .974, TLI = .953, and IFI = .974, all suggesting strong model adequacy. The

Table 4. Confirmatory Factor Analysis (CFA) outcomes and bias-corrected coefficients.

					Bootstrap bias-corrected values[d]				
Item	Item Content	λ[a]	S.E.[b]	p[c]	S.E.[b]	Bias[e]	95% CI[f]		p[g]
Category 1: Environmental monitoring									
ACAS1	Proximity radar	.785	.016	<.001	.012	.000	.768	.794	<.050
ACAS2	Rear-view display	.764	.019	<.001	.013	.000	.743	.775	<.050
Category 2: Rider visibility									
ACAS3	Turn signalling device	.770	.027	<.001	.013	.001	.754	.788	<.010
ACAS4	Automated lighting system	.664	.018	<.001	.012	.000	.643	.68	<.010
Category 3: Real-time information									
ACAS5	Built-in navigation display	.797	.014	<.001	.014	.000	.784	.809	<.010
ACAS6	On-board control centre	.863	.017	<.001	.014	.001	.853	.876	<.010
Category 4: Crash-prevention assistance (CP)									
ACAS7	Balance/turning assistance system	.826	.017	<.001	.015	.001	.816	.837	<.010
ACAS8	Automated/enhanced braking system	.793	.014	<.001	.014	.000	.778	.804	<.050
Category 5: Post-crash appliances									
ACAS9	Emergency notification system	.751	.017	<.001	.014	.001	.737	.767	<.010
ACAS10	Pre-crash data storage ('black box')	.758	.019	<.001	.014	.001	.743	.772	<.010

[a]Standardised factor loading.
[b]Standard Error.
[c]All p-values were lower than .001 – all p-values in bootstrap were statistically significant/p-values lower than .050.
[d]Bootstrapped (bias-corrected) model.
[e]Bias identified (and corrected) in the item.
[f]Confidence Interval at the level 95% (lower bound – left; upper bound – right).
[g]Bootstrapped p-value.

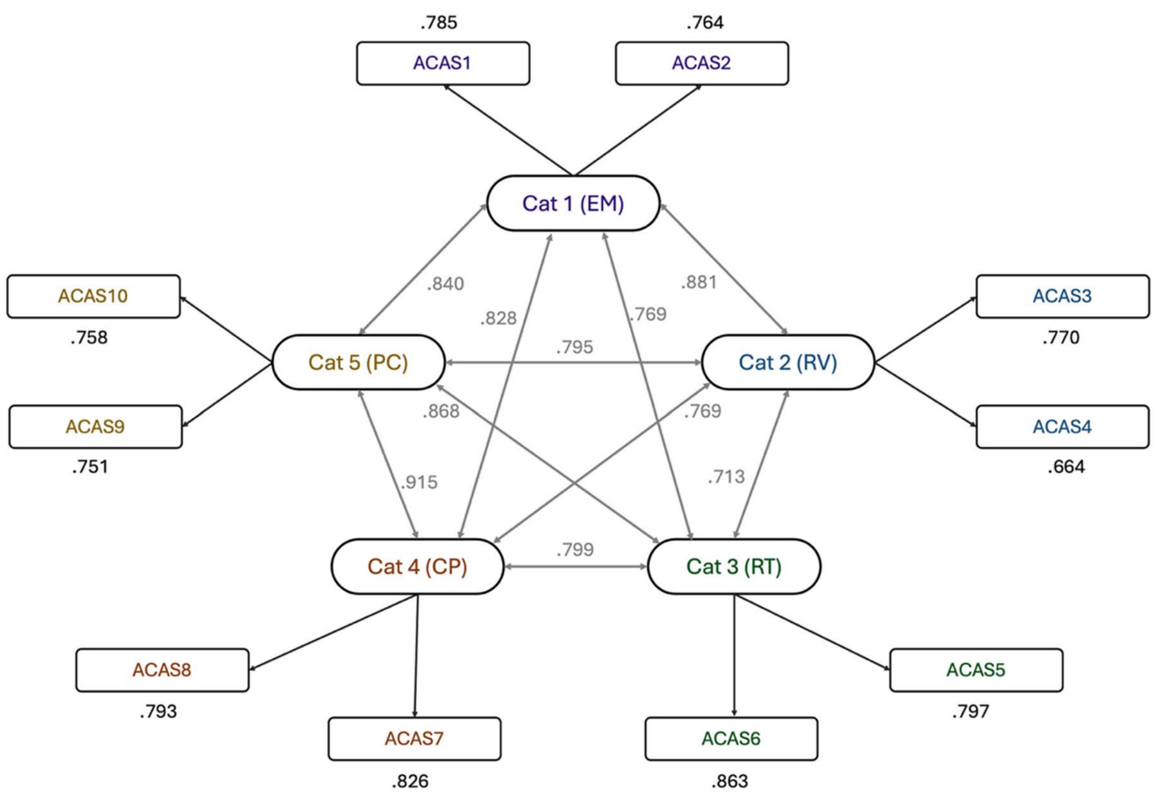


Figure 7. Graphical overview of the Confirmatory Factor Analysis (CFA) output. The shown coefficients represent standardised (lambda - λ) factor loadings.

RMSEA value of .073, with a 90% confidence interval of [.069 – .077], also indicates an acceptable approximation error.

Regarding item factor loadings (i.e. bootstrapped λ - Lambda values), the bias-corrected coefficients showed good values, ranging from .664 to .863, all statistically significant, supporting a good fit within their respective theoretical factors. The full set of these coefficients and fit metrics is presented in Table 4 and illustrated graphically in Figure 7.

Table 5. Post-hoc comparisons (Tukey's HSD) of psychological factors and acceptance ratings between categories of ACAS.

	Safety		Trust		Novelty		Ease of use		Willingness to pay		Use intention	
	(a – b)	Cohen's *d*	(a – b)	Cohen's *d*	(a – b)	Cohen's *d*	(a – b)	Cohen's *d*	(a – b)	Cohen's *d*	(a – b)	Cohen's *d*
Cat 1 – Cat 2	−0.29***	−0.37	−0.35***	−0.50	0.22***	0.29	−0.39***	−0.55	−0.35***	−0.47	−0.52***	−0.59
Cat 1 – Cat 3	0.76***	0.96	0.04	0.05	0.69***	0.90	0.22***	0.31	0.04	0.05	0.21***	0.24
Cat 1 – Cat 4	0.23***	0.30	0.37***	0.51	0.11***	0.15	0.39***	0.55	0.13***	0.17	0.37***	0.43
Cat 1 – Cat 5	0.34***	0.43	0.29***	0.41	0.25***	0.32	0.23***	0.32	0.09***	0.11	0.37***	0.43
Cat 2 – Cat 3	1.05***	1.2	0.39***	0.55	0.47***	0.61	0.61***	0.85	0.39***	0.52	0.73***	0.88
Cat 2 – Cat 4	0.53***	0.67	0.72***	1.01	−0.11***	−0.14	0.78***	1.10	0.48***	0.64	0.89***	1.02
Cat 2 – Cat 5	0.63***	0.81	0.65***	0.91	0.02	0.03	0.62***	0.87	0.44***	0.58	0.89***	1.02
Cat 3 – Cat 4	−0.52***	−0.67	0.33***	0.46	−0.58***	−0.75	0.17***	0.24	0.09***	0.12	0.16***	0.19
Cat 3 – Cat 5	−0.42***	−0.53	0.26***	0.36	−0.44***	−0.58	0.01	0.02	0.05**	0.07	0.16***	0.19
Cat 4 – Cat 5	0.11***	0.14	−0.72***	−0.10	0.14***	0.18	−0.16***	−0.23	−0.04*	−0.06	<.01	<.01

Notes: *p <.05, **p <.01, ***p <.001; (a – b) = Mean difference; Cohen's *d* = Effect size; Cat 1 = Environmental monitoring, Cat 2 = Rider visibility, Cat 3 = Real-time information, Cat 4 = Crash-prevention assistance, Cat 5 = Post-crash appliances.

Table 6. Ordinal logistic regression for willingness to pay and use intention for different ACAS types.

	Willingness to pay					Use intention				
	ACAS Group 1	ACAS Group 2	ACAS Group 3	ACAS Group 4	ACAS Group 5	ACAS Group 1	ACAS Group 2	ACAS Group 3	ACAS Group 4	ACAS Group 5
Block 1: Demographics										
Age		−.007***	−.009***	−.012***	−.014***			−.006***	−.004*	
Gender (0 = female, 1 = male)			.280***	.132**			−.124*	.357***	.184***	.143**
Education	−.052*		.094***				.056*	.063*		
Block 2: Cycling use										
Cycling hours per week		−.016**	.018***			.019***	.012*	.029*		.022***
Cycling performance	−.034**		−.026*	−.057***		−.047***		−.061***	−.081***	−.052***
Block 3: Acceptance of ACAS										
Safety	.534***	.360***	.738***	.264***	.549***	1.027***	.970***	.838***	.473***	.515***
Trust	.608***	.536***	.268***	1.098***	.994***	.620***	.517***	.524***	1.044***	1.143***
Novelty	.084**	.514***	.454***	−.128***		.112***	.217***	.297***		
Ease of use	.522***	.338***	.648***	.742***	.375***	.527***	.843***	.747***	.749***	.452***

Notes: *p <.05, **p <.01, ***p <.001.

4.3. Inferential statistics

4.3.1. Differences in acceptance ratings of ACAS

All ANOVAs showed a significant effect, suggesting that acceptance ratings differ across ACAS categories. The results of the post-hoc comparisons are displayed in Table 5. Results with moderate or large effect sizes with Cohen's $d > .5$ are described in the following section.

4.3.1.1. Safety. The results show a significant effect of ACAS categories on safety ratings, $F(4, 23{,}960) = 1{,}485.4$, $p < .001$, $\eta^2 = 0.20$. ACAS of the group real-time information had lower safety ratings than all other groups of ACAS. ACAS for rider visibility were rated as contributing more to safety than ACAS for crash-prevention assistance and post-crash appliances.

4.3.1.2. Trust. A significant effect of ACAS categories on trust ratings can be observed, ACAS, $F(4, 23{,}960) = 949.0$, $p < .001$, $\eta^2 = 0.14$. ACAS for rider visibility received higher trust ratings than all other groups of ACAS. Furthermore, ACAS for environmental monitoring had higher trust ratings than ACAS for crash-prevention assistance.

4.3.1.3. Novelty. Results show that novelty ratings significantly differ between categories of ACAS, $F(4, 23{,}960) = 697.4$, $p < .001$, $\eta^2 = 0.10$. ACAS for real-time information were perceived as least new and received lower novelty ratings than all other groups of ACAS.

4.3.1.4. Ease of use. Results show that the ratings for ease of use differ between categories of ACAS, $F(4, 23{,}960) = 1{,}076.1$, $p < .001$, $\eta^2 = 0.15$. ACAS for rider visibility were rated as significantly easier to use than all other groups of ACAS. ACAS for environmental monitoring were rated as easier to use than ACAS for crash-prevention assistance.

4.3.1.5. Willingness to pay. There is a significant difference in the willingness to pay for the different categories of ACAS, $F(4, 23{,}960) = 393.8$, $p < .001$, $\eta^2 = 0.06$. ACAS for rider visibility showed a higher willingness to pay than ACAS for real-time information, for crash-prevention assistance and post-crash appliances.

4.3.1.6. Use intention. Categories of ACAS significantly differ in their use intention, $F(4, 23{,}960) = 1{,}086.8$, $p < .001$, $\eta^2 = 0.15$. ACAS for rider visibility received higher use intention ratings than all other groups of ACAS.

Overall, ACAS for rider visibility received the highest acceptance ratings and generally ranked higher than the other categories of ACAS. Specifically, ACAS for environmental monitoring also had high acceptance ratings and occasionally ranked higher than the other groups of ACAS. At the lower end were ACAS for real-time information, which often had significantly lower acceptance ratings than the other ACAS.

4.3.2. Effect of sociodemographics, cycling use, and psychological factors on acceptance

All regression analyses were conducted using hierarchical ordinal logistic models. For clarity and conciseness, only the results of the final Model 3 are reported (see Table 6).

4.3.2.1. Willingness to pay. Age shows a negative association with willingness to pay across ACAS from Group 2, 3, 4, and 5, indicating that younger people are more likely to pay for these ACAS. Gender shows a positive association with ACAS from Groups 3 and 4, demonstrating that men are more likely to pay for these ACAS. Education shows an inconsistent effect: It is a negative predictor for ACAS from Group 1, indicating that lower education level leads to higher willingness to pay for ACAS for environmental monitoring. Yet it is a positive predictor for ACAS from Group 3, indicating that higher education level leads to higher willingness to pay for ACAS for real-time information.

Cycling hours per week have a mixed effect across different groups of ACAS: While cycling hours are a negative predictor for ACAS from Group 2, it is a positive predictor for ACAS from Group 3. This suggests that less frequent cyclists have a higher willingness to pay for ACAS for rider visibility, yet more frequent cyclists have a higher willingness to pay for ACAS for real-time information. Cycling performance shows a consistent negative association with willingness to pay across ACAS Groups 1, 3, and 5. This demonstrates that people with lower self-assessed cycling skills are more likely to pay for ACAS for environmental monitoring, real-time information, and crash-prevention assistance.

The psychological factors safety, trust, and ease of use are positive predictors of the willingness to pay for all five groups of ACAS. Hence, the more ACAS are perceived as safe, reliable, and easy to use, the more likely cyclists are to pay for them. Trust has a particularly large effect on the willingness to pay for ACAS for crash-prevention assistance and post-crash appliances. Safety has a large effect on ACAS for real-time information and ease of use has a large effect on ACAS for crash-prevention assistance. Novelty has a mixed effect with positive associations for ACAS from Groups 1, 2, and 3, and a negative association with ACAS from Group 4. Thus, the more ACAS for environmental monitoring, rider visibility, and real-time information are seen as novel, the higher the willingness to pay. However, when it comes to ACAS for crash-prevention assistance, the more they are seen as novel, the lower the willingness to pay.

4.3.2.2. Use intention. Age is negatively associated with the intention to use ACAS from Groups 3 and 4, indicating that younger people are more likely to use ACAS for real-time information and crash-prevention assistance. Gender shows an inconsistent effect: It has a positive association with ACAS from Groups 3, 4, and 5, indicating that men are more likely to use ACAS for real-time information, crash-prevention assistance, and post-crash appliances. However, gender has a negative association with ACAS from Group 2, showing that women are more likely to use ACAS for rider visibility.

Education is a positive predictor for the intention to use ACAS from Groups 2 and 3, that is, a higher education level leads to higher use intention for ACAS for rider visibility and real-time information.

Cycling intensity (i.e. riding hours per week) shows a consistent positive association with use intention across ACAS Groups 1, 2, 3, and 5. This suggests that more frequent cyclists have a higher intention to use ACAS for environmental monitoring, rider visibility, real-time information, and post-crash appliances. Contrarily, cycling performance shows a consistent negative association with use intention across ACAS Groups 1, 3, 4, and 5. Hence, people with lower self-assessed cycling skills are more likely to use ACAS for environmental monitoring, real-time information, crash-prevention assistance, and post-crash appliances.

Similar to the regression models for willingness to pay, the factors safety, trust, and ease of use are positive predictors for use intention of all five groups of ACAS. Hence, the more ACAS are perceived as safe, reliable, and easy to use, the more likely cyclists are to use them. As with willingness to pay, trust has a particularly large effect on the intention to use ACAS for crash-prevention assistance and post-crash appliances. Safety has particularly large effects on the use intention of ACAS for environmental monitoring, rider visibility, and real-time information. Ease of use has a large effect on ACAS for rider visibility, real-time information, and crash-prevention assistance. Novelty has the smallest positive associations with use intention and only with three groups of ACAS: environmental monitoring, rider visibility, and real-time information.

5. Discussion

The aim of this study was to investigate the acceptance of five different categories of Advanced Cyclist Assistance Systems (ACAS) across 19 European countries. To this end, quantitative data from an online survey on cycling behaviour and technology adoption was analysed. Acceptance was measured in two dimensions: willingness to pay and use intention. Additionally, the study explored how sociodemographic characteristics, cycling use, and psychological factors influence ACAS acceptance. Overall, the results highlight that ACAS technologies are evaluated differently depending on both the specific category and the features they offer. To present the key findings and discuss the main ideas developed in this study in the context of existing literature, this discussion will follow the two preliminary hypotheses that guided the research.

5.1. Acceptance of ACAS by cyclists

The first hypothesis of this study suggested that cyclists would report higher acceptance for ACAS categories focused on visibility enhancement and crash-prevention assistance, compared to categories such as real-time information or post-crash assistance. Our results provide coherent support for this hypothesis. Although ACAS have not yet seen widespread adoption, particularly in terms of specific functionalities, those assistance systems aimed at improving rider visibility and providing crash-prevention features received the highest levels of acceptance.

On a practical level, these results suggest that European cyclists prioritise safety features that directly reduce the risk of accidents, particularly those that enhance their visibility to other road users. In other words, cyclists appear to prefer simple, functional solutions that have an immediate and direct impact on their safety, rather than more complex systems offering indirect or less immediate benefits. It is also notable that cyclists generally show a relatively low willingness to pay for ACAS with more advanced functionalities. This finding resonates with previous research on both advanced assistance systems for road users, which has highlighted a lack of understanding and psychological concerns, such as confidence, fear of distractions, and the potential for errors, as key barriers to the adoption of onboard automation technologies (Damsara and De Barros 2025; Lijarcio et al. 2019; Oviedo-Trespalacios 2024; Oviedo-Trespalacios, Tichon, and Briant 2021).

Furthermore, this preference for visibility-related features is consistent with previous studies suggesting that safety-related functionalities are typically more valued than more complex technological solutions (Greenwood, Lenneman, and Baldwin 2022; Kapousizis, Ulak, and Geurs 2023). Cyclists seem to favour simple systems that provide clear and direct safety benefits, rather than those that offer complex or indirect advantages. This preference could also reflect an overestimation bias, as proposed by Moore and Healy (2008), where cyclists may overestimate their skills and assume that improving visibility is sufficient to mitigate road risks. Additionally, self-serving attributions might contribute to this pattern, as cyclists may be more likely to attribute safety-related incidents and their causing risks to external factors (e.g. other road users) rather than their own actions, which could explain the lower acceptance of more sophisticated ACAS functionalities designed to detect and avoid hazards (Stewart 2005; Useche and Llamazares 2022).

5.2. Factors influencing the acceptance of ACAS

Our second hypothesis suggested that sociodemographic characteristics, cycling frequency, and psychological factors would significantly influence the acceptance of ACAS. The findings of this study largely support this hypothesis, revealing that both demographic variables and cycling behaviours impact cyclists' willingness to pay for and use ACAS. Specifically, younger cyclists and those who cycle more frequently showed higher acceptance across all ACAS categories. This supports the notion that technology adoption is more prevalent among younger individuals and frequent users, who are more accustomed to technology and have a greater understanding of its benefits (Hauk, Hüffmeier, and Krumm 2018).

Gender differences were also observed, with men generally showing higher acceptance for most types of ACAS, except for the visibility-related systems, where women expressed higher willingness to use them. This aligns with prior studies on Advanced Driver Assistance Systems (ADAS), which found higher technology acceptance among men (Son, Park, and Park 2015). The higher acceptance of visibility-enhancing ACAS among women can be interpreted as a result of more risk-averse cycling behaviour, as women generally self-report lower levels of risky behaviour in traffic (Özkan and Lajunen 2006). This finding suggests that women prioritise safety, particularly through technologies that improve their visibility to other road users.

Cycling frequency also played a role in ACAS acceptance. More frequent cyclists demonstrated a greater willingness to adopt ACAS, possibly because they perceive greater benefits from these technologies due to their higher exposure to cycling-related risks. Additionally, cyclists who rated their cycling skills as lower were more inclined to use ACAS, suggesting that such technologies may serve as compensatory tools for enhancing cycling confidence.

Psychological factors, including perceived safety, trust, and ease of use, were also found to be important predictors of ACAS acceptance. Trust, in particular, emerged as a key determinant, especially for systems designed to prevent crashes and assist post-crash. Cyclists who had greater trust in technology were more likely to accept and be willing to pay for ACAS. This is consistent with findings in the ADAS literature, where trust plays a significant role in technology adoption (Bosurgi et al. 2023). Interestingly, novelty did not significantly influence ACAS acceptance and showed a negative relationship with willingness to pay ACAS group 4. We assume that this negative association is related to the fact that novelty can also be perceived adversely since novel products demand consumers to adapt and effectively use a new technology (Mugge and Dahl 2013). This suggests that more complex systems, which may overwhelm users or be perceived as too difficult to use, could discourage adoption. The negative association is only found for ACAS group 4 (balance/turning assistance system, automated/enhanced braking system) integrating technologies that have been rated to relatively novel and indeed demand for certain skills and expertise to use them. This finding supports the notion that simplicity and reliability may constitute critical reasons for encouraging the uptake of new technologies (Kapousizis, Ulak, Geurs, et al. 2023; Useche, Alonso, and Oviedo-Trespalacios 2024; Useche, Faus, and Alonso 2024).

Moreover, the cross-country variation observed in both willingness to pay and intention to use ACAS suggests that national context and macrosocial variables play a relevant role in shaping acceptance patterns. Previous research has highlighted that differences in cycling infrastructure, traffic regulations, and cultural attitudes towards cycling may substantially affect how new technologies are perceived and adopted (Marqués et al. 2015; Pucher and Buehler 2008; Schepers et al. 2014; Useche et al. 2025). Our findings align with this line of evidence, indicating that ACAS acceptance cannot be understood solely as an individual-level phenomenon but is also embedded within broader infrastructural and cultural environments. Future research could benefit from incorporating national or city-level indicators of cycling systems to provide a more detailed explanation of these differences.

5.3. Limitations of the study

While this study provides valuable insights into the acceptance of Advanced Cyclist Assistance Systems (ACAS), several limitations must be acknowledged when interpreting the results. First, the study relies on a sample of cyclists from different European countries but does not account for differences in the prevalence of cycling and the availability of cycling infrastructure across countries. These differences could influence perceptions of ACAS and their acceptance, as cycling behaviour and attitudes may vary significantly depending on local infrastructure and cycling culture (Martínez-Díaz and Arroyo 2023; Useche et al. 2018; Xu et al. 2025).

Second, the data were collected by multiple researchers using various sampling methodologies, ranging from convenience sampling to representative sampling obtained through market research panels. This data collection approach also limits the inclusion of minority user profiles, such as non-binary and gender nonconforming individuals, who are more commonly reached through targeted convenience sampling procedures (Ivanova and O'Hern 2024). Although demographic differences across samples were noted, these were addressed by including demographic variables in the regression models. However, the variability in sampling methodologies may still introduce some biases, which should be considered when interpreting the findings.

Another limitation related to the recruitment procedures concerns the inclusion of underrepresented groups. The recruitment method employed did not allow for a fair representation of cyclists with diverse backgrounds. Future research should address this shortcoming by considering for example targeted sampling strategies.

The study evaluated ten specific ACAS, each with predefined functionalities. These detailed descriptions likely helped participants visualise their use, thus enhancing the ecological validity of the study. However, this specificity also limits the generalisability of the findings. If different ACAS had been assessed, or if additional features had been included, the levels of acceptance might have varied. Moreover, actual use or ownership of these ACAS was not measured, as they consist of emerging technologies that are not yet widely adopted. If participants had prior experience with these technologies, their acceptance ratings might have been influenced by their familiarity, potentially introducing a bias in their responses (Podsakoff et al. 2003). As these systems become more available, future studies should also include objective data, to validate self-reports. Also, future research could extend the findings by investigating actual use of ACAS to incorporate real-world experience with these technologies and thereby validating the findings. Moreover, an observational study could also support to gain insights on the impact of these systems on cycling safety.

Further, some inconsistent findings – such as the negative association between novelty and willingness to pay for ACAS systems in group 4 – could be further investigated using a qualitative approach.

An additional limitation is the potential impact of Common Method Biases (CMBs), as the study relied on self-reported data from a single source. CMBs arise when variations in responses are attributable to the measurement method rather than the actual constructs being studied (Podsakoff et al. 2012). In this case, participants' self-reports regarding ACAS acceptance may have been influenced by biases related to the survey format, leading to inflated or socially desirable responses. Furthermore, memory flaws could have affected participants' ability to recall their experiences accurately, particularly since they were asked to rate hypothetical technologies that may not yet be in widespread use (García-Bajos, Migueles, and Aizpurua 2018; Selaya, Vilariño, and Arce 2024).

These limitations should be considered when interpreting the results of this study. Future research could address these issues by using experimental or longitudinal designs, incorporating objective measures of ACAS use, and reducing the potential for CMBs by employing multi-method approaches.

6. Conclusion

This study examined the acceptance of five categories of Advanced Cyclist Assistance Systems (ACAS) across 19 European countries, considering both functional types and user-related factors. Using data from a multi-country sample, it assessed cyclists' willingness to pay for and intention to use these technologies, offering an overview of current attitudes towards ACAS in the European cycling context.

In line with the study hypotheses, the findings suggest that cyclists assign higher acceptance to systems aimed at improving rider visibility and crash prevention – those perceived as offering direct safety benefits. While other categories, such as real-time information or post-crash assistance, received comparatively lower ratings, the overall pattern reflects a preference for straightforward, safety-oriented solutions over more complex or indirect technological aids.

Regarding the influence of individual factors, the results also support the hypothesis that sociodemographic characteristics and psychological variables play a role in shaping ACAS acceptance. Age and gender differences were observed, with younger participants and women more frequently valuing visibility-enhancing technologies. In addition, frequent cyclists and those with lower self-rated skills were more likely to express interest in using ACAS, particularly those that enhance safety. Psychological factors such as perceived safety, trust, and ease of use also contributed to differences in acceptance levels, with novelty having a limited or inconsistent role.

Finally, this study highlights the relevance of evaluating not only technological functionalities but also user-related and contextual aspects when considering the development and promotion of ACAS. As the integration of these technologies into everyday cycling practice advances, understanding their perceived value from the user's perspective remains key to ensuring both their design relevance and effective adoption.

As ACAS constitute one of several factors influencing cycling safety, the current findings can inform policymakers in promoting the integration of safety-related bicycle technologies. Particularly, systems aimed at improving rider visibility and crash prevention that are backed with high acceptance and directly linked to cyclists' safety could be integrated as compulsory in new bike related legislations. Although, prioritising safe cycling infrastructure remains priority, the insights of this study shows the potential of technological aids that offer direct safety benefits to cyclists.

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Author contributions statement

CRediT: **Nora Studer**: Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing; **Dorothea Schaffner**: Conceptualization, Investigation, Supervision, Writing – original draft, Writing – review & editing; **Steve O'Hern**: Supervision, Writing – original draft; **Trond Nordfjærn**: Writing – original draft; **Francisco Alonso**: Writing – original draft; **Predrag Brlek**: Writing – original draft; **Mile Cavar**: Writing – original draft; **Javier Gene-Morales**: Writing – original draft; **Jozef Gnap**: Writing – original draft; **Giuseppe Guido**: Writing – original draft; **Milad Mehdizadeh**: Writing – original draft; **Mette Møller**: Writing – original draft; **Dimitrios Nalmpantis**: Writing – original draft; **Mihai R. Niță**: Writing – original draft; **Ksenia Shubenkova**: Writing – original draft; **Sergio Traficante**: Writing – original draft; **Zermena Vazne**: Writing – original draft; **Katrina Volgemute**: Writing – original draft; **Sergio A. Useche**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing.

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