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## **Safe on the Road – Does Advanced Driver-Assistance Systems use affect Road Risk Perception?**

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## **Safe on the Road – Does Advanced Driver-Assistance Systems use affect Road Risk Perception?**

A major goal of advanced driver-assistance systems (ADAS) deployment is higher road safety. However, these systems are only as safe as users handle them. This article presents a study evaluating the links between the use of ADAS and road risk perception. 101 drivers were invited to evaluate accident probability and risk controllability and to indicate whether they were using ADAS or not. Results show that the use of ADAS decreases perceived accident probability and increases perceived controllability for risky driving situations. Since the degree of automation in ADAS is still low nowadays, it is important to discuss the importance of human factors for the purpose of a safer implementation.

Keywords: Advanced Driver-Assistance Systems (ADAS) use; Risk Perception; Road Risk; Road Safety

### **Practitioner Summary**

Understanding risk perception is important to prevent dangerous situations that might occur when individuals feel especially protected, e.g. through ADAS use.

Efficient accident prevention requires a common understanding that ADAS are not fool proof. Higher safety through ADAS use can only be successful if drivers learn how to handle ADAS safely.

## **Introduction**

Advanced Driver-Assistance Systems (ADAS) are in constant development and their use increases worldwide. As shows an international study with over 5000 participants from 109 countries (Kyriakidis, Happee & de Winter, 2015), respondents expect most cars to drive automatically on public roads in 2030. In September 2015, the Federal Ministry of Transport and Digital Infrastructure in Germany launched a digital platform to test autonomous cars on a dedicated section of the most frequented Bavarian motorway under real traffic conditions (German: Bundesministerium für Verkehr und digitale Infrastruktur [BMVI], 2017). The project's aim is to test an autonomous and digitalized traffic system with interconnected infrastructure. Higher driver comfort, more ecological driving and efficient traffic flow as well as significant accident reductions in numbers and severity are expected. Before fully autonomous cars can be implemented, the European Commission (2010) and the European Parliament (2017) decided on an initiative to improve traffic safety through higher ADAS deployment. The tendency to buy cars with integrated ADAS is estimated to increase by 20% from 2016 to 2020 (Choi, Thalmayr, Wee & Weig, 2016). Nowadays, car manufacturers offer a variety of car integrated ADAS in diverse designs, automation degrees and price categories. Depending on their automation degree, they impact the driver's activity differently. ADAS increase drivers' comfort and safety by informing, warning and actively supporting guidance and stabilization of the vehicle (Knoll, 2010a). Despite the technical progress of modern ADAS, their automation degree is relatively low. Consequently, driving still requires active driver implication. For this reason, studying human factors in ADAS use and their possible consequences on safety is necessary. In the present study, we aim to evaluate how ADAS use affects road risk perception of drivers. More precisely, we aim to understand if using ADAS is likely to provoke

beliefs and overconfidence in the supporting systems designed to minimize risks and whether this affects road risk perception. Furthermore, we are interested in the role of gender and ADAS use in road risk perception.

### *Advanced driver-assistance systems and road safety*

Nowadays, the most deployed ADAS are Adaptive Headlights, Blindspot Monitoring, Obstacle and Collision Warning, Lane Keeping Support, Automatic Emergency Braking and Eco Driving Support systems (Kyriakidis, van de Weijer, van Arem, & Happee, 2015). In the present study, we focus on four ADAS considered to have similar automation levels (Society of Automotive Engineers [SAE], 2018). These four systems include Lane Keeping Support, Blind Spot Monitoring, Adaptive Cruise Control and Automatic Emergency Braking. Lane Keeping Support (LKS) systems detect reflective lane markers in front of the car and alert the driver by haptic, visual or audible signals if the vehicle crosses the lane and no side turn signals or steering movements are registered (Varghese & Boone, 2015). On a higher automation level, the system briefly takes over to guide the vehicle back into the lane. Sternlund, Rizzi, Lie and Tingvall (2017) showed that LKS significantly reduces driver injury risks in head-on and single-vehicle crashes. In a simulation based on real crash data in the US, Kusano and Gabler (2015) found that the use of LKS could have prevented 11 to 23% of accidents at 72 km/h; the accident prevention percentages even double when speed is reduced to 51 km/h. According to Klunder et al. (2009), LKS could help decrease by 9% the number of accidents within the EU25 level. As to Blind Spot Monitoring (BSM) systems, they alert drivers whenever another vehicle appears in their blind spot. Through camera, ultrasonic, radar- or lidar technology, objects entering the blind spot are detected (Trappe, 2017; Varghese & Boone, 2015). BSM mainly serves drivers prior to lane

change or drive-off. They either warn or intervene actively by keeping the vehicle in lane. According to Cicchino (2018), vehicles with integrated BSM were significantly less involved in lane crash. A detailed crash analysis by Jermakian (2011) shows that the use of BSM could prevent 6.78% of all annual passenger vehicle crashes in the United States. In Adaptive Cruise Control (ACC) systems, sensors measure the relative speed of the vehicle (Ligthart, Ploeg, Semsar-Kazerooni, Fusco, & Nijmeijer, 2018). Long-range radars detect the area in front of the vehicle (Knoll, 2010b). By the means of the time delta, ACC automatically maintains a preset security distance with a preceding vehicle. ACC systems are designed for comfortable and convenient driving but do not prevent crashes in emergency situations (Li, Li, Wang, Wang, & Xing, 2017). However, Benmimoun, Zlocki and Eckstein (2013) found that ACC use reduces close approaching manoeuvres and critical situations on motorways to 73 % and therefore could prevent up to 67% harsh braking events. Finally, Automatic Emergency Braking (AEB) systems help to prevent rear-end crashes in emergency situations. Through low-range and low-resolution lidar (Bengler et al., 2014) they detect the preceding vehicle and calculate the braking distance in relation to the speed. Forward collision systems warn the driver to brake in time. However, they are often combined with an AEB system that automatically brakes in an emergency. According to Cicchino (2017), the combination of forward collision systems and AEB is more effective and can prevent up to 50% of rear-end striking crashes in the US. In a meta-analysis, Fildes, et al. (2015) conclude on a collision reduction of 38% in rear-end crashes using low speed AEB technology in urban and rural areas.

### ***Automation and human behaviour***

Even though high safety benefits are expected from ADAS use, potential adverse effects

due to automation should be addressed. Results from fundamental and experimental research in aviation show that automation increases human factor challenges such as changing performance, situation awareness, operator workload (Endsley, 1999) and manual deterioration (Bainbridge, 1983). In the area of ADAS, Ward, Fairclough and Humphreys (1995) found that participants, trained to use ACC systems, had problems keeping security distances and their vehicle in lane when driving without the system. It is therefore very likely that manual driving becomes generally less accurate after a system failure if one uses ADAS on a regular basis. Consequently, the situation can quickly turn dangerous if a system fails during an emergency, as manual abilities are deteriorated, and the driver must take over commands suddenly to react in time. Next to manual performance deterioration, multitasking is another automation-relative human factor challenge as it implies the driver's ability to execute other tasks next to driving. Multitasking is often understood as simultaneous task handling, quick task switching (Waller, 1997) or attempting to manage a rapid succession of tasks (Burak, 2012). Past studies suggest that easier tasks (Kahnemann, 1973) and training (Duncan & Mitchell, 2015; Schumacher et al., 2001) can facilitate dual tasks and multitasking. Although it is tempting to think that ADAS use can support the execution of several tasks in parallel, Lansdown, Brook-Carter and Kersloot (2004) argue that executing these tasks can lead to higher mental workload for drivers and task performance impairment when having to deal with several non-relevant driving activities next to driving. One should not forget that situations, which drivers were not trained to handle on a regular basis, can emerge unexpectedly. Such situations require immediate driver reaction and can have severe consequences if drivers can't react in time because of mental overcharge or distraction.

### ***Research objectives and hypotheses of the present study***

According to Choi et al. (2016), the tendency to buy cars with integrated ADAS is estimated to increase by 20% from 2016 to 2020. Theoretically, these numbers should result in higher road safety. In Germany, where the present study took place, car manufacturers are eagerly engaged in the development of ADAS. In 2015, German drivers bought more cars than the previous year (Süddeutsche Zeitung, 2016). Even though it is difficult to establish a direct connection, it is important to note that, according to the Federal Statistical Office of Germany (German: Statistisches Bundesamt [Destatis], 2016), the number of fatal accidents decreased by 6.9% in 2016. It is however curious to find that the number of injured individuals due to a road accident increased by 8.6%. Compared to 2015, a total increase of 3.3% in road accidents was observed (Destatis, 2016). We believe that the drivers' perception of ADAS could be one indication to explain such discrepancy. Even though ADAS technology is often associated with higher comfort and better security standards for drivers, past research show that automation can be accompanied by risks. Yet, the current state of art does not allow deployment of fully automatic ADAS amongst the general driving population. Therefore, the handling of modern ADAS demands high driver implication. The way drivers perceive ADAS and especially how drivers perceive risk in general provides important information about the attitudes and actions they are likely to adopt in risky situations. Besides the challenge to cooperate adequately with ADAS, biased perceptions through blind confidence in the systems' abilities could push drivers to be less vigilant and to take fewer precautions. In aviation, complacency effects (Knapp & Vardamann, 1991; Wiener & Curry, 1980) and overreliance (Parasuraman & Riley, 1999) through automation relate to human error due to the feeling that everything is right (Parasuraman & Manzey, 2010). Concerning road traffic,



a study on auto safety regulation suggests that higher safety standards did not result in a decrease of fatal accidents on highways because drivers took greater accident risk (Peltzman, 1975). Risk homeostasis theory (Wilde, 1982; 1998) postulates that accident rates remain constant due to human adjustment to risk. Within this framework, a field study demonstrated that taxi drivers using anti-lock braking systems (ABS) had less accidents due to full braking compared to taxi drivers not using ABS but compensated this safety gain by an increase in diverse other road accidents (Aschenbrenner, Biehl & Wurm 1992). Moreover, Brookhuis, de Waard and Janssen (2001) refer to complacency effects as an over-reliance on an automated system. Moreover, drivers could perceive an illusionary feeling of safety and allow the system to take over tasks on purpose or even test the systems' limits (BMVI, 2015). Both adverse effects come along with lower road risk perception. Several authors (Brewer et al., 2007; Ivers et al., 2009; Kouabenan, 2002; Kouabenan, 2006; Slovic, Fischhoff, & Lichtenstein, 1981; Weinstein et al. 2007) demonstrated the benefits of studying risk perception to better understand and influence safety behaviour. As states Kouabenan (2006), the way an individual perceives risks indicates not only how the concerned individual positions oneself but also how he or she will deal with risks. In a meta-analysis of 43 studies on the relationship between risk perception and preventive behaviours, Brewer et al. (2007) showed that perceptions about the likelihood of risk, the feeling of vulnerability and risk severity were significant predictive indicators of preventive behaviour. Furthermore, a longitudinal study by Ivers et al. (2009) on a sample of 20.822 novice drivers demonstrated that higher levels of perceived risk were related to increased safety behaviours and fewer crashes. However, no studies have investigated the links between the use of ADAS and road risk perception so far. Within the scope of this study, our research question

addresses the influence of ADAS use on road risk perception. Based on previous literature and context analysis, we propose the following hypotheses:

H<sub>1</sub>: Drivers who use ADAS perceive lower probability of being personally involved in an accident than drivers who do not use ADAS.

H<sub>2</sub>: Drivers who use ADAS perceive higher controllability of risky situations than drivers who do not use ADAS.

## **Methods**

### ***Participants***

A total number of 101 (40 female) German drivers from the Munich metropolitan area took part in the study. Within the scope of this study, drivers were assigned to the group ADAS user if they used at least two out of the four ADAS in their vehicle: Lane Keeping Support (LKS), Blind Spot Monitoring (BSM), Adaptive Cruise Control (ACC), automatic emergency braking (AEB). If they were not using any ADAS in their vehicle, they were assigned to the group drivers not using ADAS.

### ***Materials***

To better understand drivers' perception of road risks and risky driving behaviours, we firstly conducted a pre-inquiry among three ADAS users and three drivers not using ADAS. Participants were asked to describe risky driving behaviours on different German roads: Motorways, two-lane expressways, state- and district roads as well as streets within municipalities and cities. A qualitative analysis revealed 13 driving behaviours that were compared to an official list of driver misconduct leading to road accidents on German roads in 2013 (Destatis, 2014). Based on the 13 driving behaviours identified in the participants' descriptions and in the official list, the scales

for perceived accident probability and perceived risk controllability were constructed. Both likert-type scales contained the same 13 items (cf. **Measurement scales and instructions**) in the same randomly sorted order. Concerning the perceived accident probability scale, participants were invited to estimate the probability of being personally involved in an accident by performing the described driving behaviour on a likert-type scale ranging from 1 = low probability to 5 = high probability. On a second scale, drivers were invited to assess their perceived risk control of driving behaviours on a likert-type scale ranging from 1 = low controllability to 5 = high controllability. After evaluating accident probability and risk controllability, participants were asked to carefully read the description of each ADAS used in the study. The ADAS descriptions were taken from a website, established by the German Road Safety Council and their partners to road safety with ADAS (Deutscher Verkehrssicherheitsrat [DVR], 2020). For each of the presented ADAS, participants had to indicate whether they were using the described ADAS in their main vehicle in daily life or not at all. The question on gender was addressed by the end of the questionnaire, as well as a control question on the possession of a valid driver's licence. In a separate section, respondents could comment on the questionnaire.

### ***Procedure***

Participants were mostly encountered at their workplace, in two public and two private companies located in the Munich metropolitan region. Printed questionnaires in German language were distributed to volunteers in each of the four companies. In order to increase sample size especially among female drivers, additional participants were encountered at their homes to take part in the study. The questionnaires guaranteed confidentiality through anonymisation. Participants completed the questionnaires

individually. The filled-out forms were collected locally or sent back by mail.

## **Results**

Data were analysed with IBM SPSS Statistics 25. First, to better contextualize the set of variables intended to measure risk perception via perceived accident probability and perceived risk controllability, results of **parallel and exploratory** factor analyses and scale reliability for both scales are presented. Second, overall descriptive statistics are shown. Third, we present the relationship between both dependent variables. To conclude, the results of statistical hypothesis testing are shown.

### ***Parallel analysis (PA) and exploratory factor analysis (EFA) method on used measurement scales***

To decide for an adequate extraction method, both scales were checked for normality (Fabrigar, Wegener, MacCallum, & Strahan, 1999). Kurtosis and skewness values indicated no normality violations. **To determine how many factors should be retained in the exploratory factor analysis, we conducted a parallel analysis (PA) using a SPSS script by O'Connor (2000, 2020). We specified to run one thousand parallel datasets based on permutations of the raw data set, setting the desired percentile of the distribution and random data eigenvalue to 95. We decided on a principal axis/common factor analysis approach. The decision on the number of common factors to retain was based on Fabrigar et al. (1999): “a model is specified with the same number of common factors as real eigenvalues that are greater than the eigenvalues expected from random data” (p. 279). To understand how items loaded on each factor, we specified the number of factors identified in the PA and performed a maximum likelihood extraction (Costello & Osborne, 2005; Fabrigar & Wegener, 2012, pp. 98-99) for the 13 items of each scale. As items often correlate in psychology and consequently oblique rotation**

methods are the more adequate option (Costello & Osborne, 2005; Preacher & MacCallum, 2003), we chose a direct oblimin rotation. Coefficients were retained if their values were equal or above .40 (Pituch & Stevens, 2015a, p. 346). No indices for multicollinearity were found in neither scale at any time the **factor analyses** were run. Since communalities of the initial solutions always indicated values above .20, all items were retained before proceeding to further item selection. Retained items for both scales are described in **Table 1** and **Table 2**. Items in the perceived accident probability scale represent mostly driving behaviours that implicate other road users, whereas items in the perceived controllability scale represent mostly individual driving behaviours with few implications of other road users.

*PA and EFA for the 13-item scale on perceived accident probability and scale reliability*

PA results of the 13-item scale on perceived accident probability indicate two raw data eigenvalues above the 95<sup>th</sup> percentile estimates from the random data (cf. Figure 1). In the factor analysis, we consequently specified two factors to extract. Sampling adequacy was “middling”; KMO = .779 (Kaiser & Rice, 1974). Bartlett’s test of sphericity was significant  $\chi^2(78) = 498.66, p < .001$ . PR4 “driving when tired” did not load on any factor above .40. PR5 “exceeding the speed limit”, PR9 “driving at full throttle when speed is not limited” and PR12 “operating centre console screen manually” had a factor loading above .60 on factor 2. PR6 “letting go of steering wheel from time to time” a factor loading of .495 on factor 2. Since a fair interpretation of a factor with a sample size fewer than 300 observations should contain at least four variables with loadings above .60 (Guadagnoli & Velicer, 1988), we chose to not retain factor 2 and eliminated PR 4 “driving when tired”, PR 5 “exceeding the speed limit”, PR6 “letting go of steering wheel from time to time”, PR9 “driving at full throttle when

speed is not limited” and PR12“operating centre console screen manually”. A re-run of the PA indicated to retain one factor. The one-factor solution EFA shows a meritorious sampling adequacy  $KMO = .843$ . Bartlett’s test of sphericity was significant  $\chi^2 (28) = 265.35, p < .001$ . The solution indicated one factor explaining 48.4% of the variance. The factor matrix shows at least four variables that load above .60 on the factor and is therefore interpretable according to the given sample size (Guadagnoli & Velicer, 1988). However, the average of the extracted communalities is .41. For sample sizes small as 100 observations, the average of extracted communalities should be at least 0.5 (McCallum, Widaman, Zhang, & Hong, 1999). In conclusion, we kept eight items for measuring perceived accident probability, as summarized in Table 1. Good reliability was obtained for the perceived accident probability scale (8 items,  $\alpha = .845$ ).

PA results of the 13-item scale on perceived risk controllability indicate two raw data eigenvalues above the 95<sup>th</sup> percentile estimates from the random data (cf. Figure 2). In the factor analysis, we consequently specified two factors to extract. Sampling adequacy was “meritorious” (Kaiser & Rice, 1974);  $KMO = .838$ . Bartlett’s test of sphericity was significant  $\chi^2 (78) = 456.95, p < .001$ . CO7 “Not stopping in front of a crosswalk” and CO8 “Not looking back over one’s shoulder when changing lane” did not load on any factor above .40. CO2 “Overtaking in restricted visibility conditions” and CO13 “Using cell phone handheld” were the only two items loading on factor 2. Since a fair interpretation of a factor with a sample size fewer than 300 observations should contain at least four variables with loadings above .60 (Guadagnoli & Velicer, 1988), we chose not to retain the items that load on factor 2. A re-run of the PA indicated to retain one factor. The one-factor solution factor analysis shows a meritorious sampling adequacy  $KMO = .865$ . Bartlett’s test of sphericity was significant  $\chi^2 (36) = 282.09, p < .001$ . The solution indicated one factor explaining 45.6% of the

variance. However, the average of the extracted communalities is .39. For sample sizes small as 100 observations, the average of extracted communalities should be at least 0.50 (McCallum et al., 1999). In conclusion, we kept nine items for measuring perceived risk controllability, as summarized in Table 2. Good reliability was obtained for the perceived risk controllability scale (9 items,  $\alpha = .847$ ).

(Insert Table 1 and Table 2 about here)

### *Descriptive analyses*

The study sample was composed of 61 male (60.4%) and 40 female (39.6%) drivers. 45 drivers were ADAS users (44.6%), 56 drivers (55.4%) did not use ADAS at all. Among female participants, 14 were ADAS users (35.5%) whereas 26 did not use ADAS (65.5%). 31 male participants drove with ADAS (50.8%) while 30 did not use ADAS (49.2%).

ADAS deployment was different between genders. Automatic emergency braking (AEB) was used by 25 male drivers (80.6%) compared to 10 female drivers (71.4%). Adaptive cruise control (ACC) was deployed among 24 male (77.4%) and 12 female (85.7%) drivers. 18 male ADAS users (58.1%) drove with blind spot monitoring (BSM), compared to only 5 female ADAS users (35.7%). Lane keeping support (LKS) was used by 15 male drivers (48.4%) and 9 female drivers (64.3%).

(Insert Figure 3 and Figure 4 about here)

Mean values and standard deviations of perceived accident probability according to ADAS and gender are presented in Table 3. Mean values and standard deviations of perceived risk controllability are shown in Table 4.

(Insert Table 3 and Table 4 about here)

### ***Relationship between perceived accident probability and perceived risk controllability***

As risk perception was measured by perceived accident probability and perceived risk controllability, we conducted a bivariate correlation to test their relationship. There was a **weak** negative correlation between perceived accident probability and perceived risk controllability ( $r = -.256, p < .01$ ). Driving behaviours, which were evaluated as less accident prone, were perceived as being more controllable.

### ***Statistical hypothesis testing***

Analysis of variance (ANOVA) is the most adequate procedure to test our hypotheses regarding the relationship between ADAS use, perceived accident probability and perceived risk controllability. Statistical assumptions respecting recommendations on independency, normal distribution, homogeneity of variances and group size (Pituch & Stevens, 2015b, p. 220) were met for both models. To avoid multiple comparison problems, we applied a Bonferroni correction (Gelman, Hill, & Yajima, 2012) and considered therefore to reject a null hypothesis if  $p < .025$ .

Significant differences were observed between ADAS users and drivers not using ADAS on perceived accident probability  $F(1, 99) = 5.257, p = .024, \eta^2_p = .05$ . Conforming to  $H_{1,1}$ , drivers who use ADAS perceive lower probability of being personally involved in an accident ( $M = 3.03; SD = 0.85$ ) than drivers who do not use ADAS ( $M = 3.42; SD = 0.84$ ). ADAS also significantly affects perceived risk controllability  $F(1, 99) = 7.307, p = .008, \eta^2_p = .069$ . Conforming to  $H_{2,1}$ , drivers who use ADAS perceive higher controllability of risky driving situations ( $M = 3.31; SD = 0.70$ ) than drivers who do not use ADAS ( $M = 2.92; SD = 0.72$ ).



## Discussion

The aim of the study was to explore if drivers using ADAS had generally different road risk perception compared to driver who do not use them. As we assumed, drivers using ADAS perceive the probability of being personally involved in an accident due to risky driving behaviour lower than those who do not use ADAS. Results also confirmed our hypothesis that perceived risk controllability was higher for ADAS users than for those who do not use ADAS. Concerning both results, road risk perception was lower for ADAS users compared to drivers who do not use ADAS. The lower risk perception with ADAS users could be linked to effects that are frequently associated with automation, such as complacency (Knapp & Vardamann, 1991; Wiener & Curry, 1980), over-reliance (Brookhuis et al., 2001; Parasuraman & Riley, 1999; Parasuraman & Manzey, 2010) or illusionary feelings of safety (BMVI, 2015). Since risk perception is a reliable predictor for safety behaviour (Brewer et al., 2007; Ivers et al., 2009; Kouabenan, 2002; Kouabenan, 2006; Slovic et al., 1987; Weinstein et al., 2007), these results are striking. Lower road risk perception could lead ADAS users to engage in riskier driving behaviours compared to those who do not use ADAS. This can impair the expected security benefits of ADAS use, such as preventing a significant number of road accidents (Benmimoun et al., 2013; Fildes et al., 2015; Jermakian, 2011; Klunder et al., 2009; Kusano & Gabler, 2015; Li et al., 2017). Moreover, it could explain the increase in the total number of road accidents on German roads despite a rise in both ADAS deployment (Choi et al., 2016) and sales of new cars (Süddeutsche Zeitung, 2016).

However, our study contains some limitations. First, this study was conducted with a new scale and a new sample of participants. **Parallel analysis and exploratory** factor analyses provided us information about the set of relevant variables to measure

risk perception via perceived accident probability and perceived risk controllability. Two unidimensional scales were developed within this study. Items in the perceived accident probability scale mostly represent traffic rule violations that exclusively implicate other road users, whereas items in the perceived controllability scale represent mostly individual driving behaviours that do not respect traffic rules with fewer implications of other road users. This is an interesting result but needs further investigation for validation. Moreover, relatively small sample size led us to drop items with coefficients smaller than .40 (Pituch & Stevens, 2015a, p. 346) and to not retain factors containing less than four variables with loadings above .60 (Guadagnoli & Velicer, 1988). By consequent, our models lose explanation of variance. For a robust interpretation of the factors, we suggest further studies with larger sample size. The small sample size and lack of representativeness this study sample does not allow the results to be generalized. Further studies with more representative and larger sample are recommended to potentially confirm our findings but also to assess their scope. This applies especially for research on gender effects (Charness & Gneezy, 2012; Flynn, Slovic, & Mertz, 1994; Harris, Jenkins, & Glaser, 2006), being more robust when sample size is sufficiently high to be adequately powered (Rich-Edwards, Kaiser, Chen, Manson, & Goldstein, 2018). In addition, it would be interesting to study risk perception associated specifically with each of the four types of ADAS to examine whether perceptions of accident probability and risk controllability vary according to the type of ADAS. In fact, the vehicle's response is different according to the ADAS implicated. Lane keeping support (LKS) and blind spot monitoring (BSM) react on different automation levels to take over lateral control, whereas adaptive cruise control (ACC) and automatic emergency breaking (AEB) react to take over longitudinal control. To better discriminate risk perception regarding specific ADAS among users

and drivers who do not use ADAS, it would be interesting to select three to five items per ADAS type. These items should describe risky driving situations to which the ADAS in question could take over vehicle control.

Another limit of the study is the correlational nature of the study which does not allow concluding in terms of causality (Holland, 1986). Thus, our results give no information about the causal influence of ADAS use on perceived accident probability and risk controllability. It is conceivable that constructs, which were not included in our setting, such as complacency (Knapp & Vardamann, 1991; Parasuraman & Manzey, 2010; Parasuraman & Riley, 1999; Wiener & Curry, 1980) or acceptance and acceptability (Bellet, Paris, & Marin-Lamellet, 2018; Biassoni, Ruscio, & Ciceri, 2016) could influence the relationship between ADAS and risk perception. For reliable statistical evidence of moderation and mediation processes, one should be clear about the underlying model (Muller, Judd & Yzerbyt, 2005) and find appropriated ways to test it, for instance by using driving simulators in experimental design (Wang, Cheng, Li, André, & Jiang, 2019) or improving research practices natural experiment designs (Dunning, 2008). Thanks to field tests (Lyu, Deng, Xie, Wu, & Duan 2018; Son, Park, & Park 2015), further complementary research could evaluate direct impact of ADAS use on risk perception and driving behaviours as well as simultaneously test other variables such as situation awareness, trust, or acceptance in ADAS.

## **Conclusion**

Despite these few limitations, the contributions brought by this study are noteworthy. Ideally, ADAS are expected to make driving greener, more comfortable and safer. However, their correct use still represents a serious challenge for drivers who already use them and for those who will soon. One reason is the relative low automation degree which necessarily demands active driver implication. Therefore, the introduction

of ADAS requires studies analysing the human factors involved in their use. Indeed, the way individuals perceive road risk indicates driving behaviours they are likely to adopt. Understanding risk perception is important to prevent dangerous situations that are likely to occur when individuals feel especially protected, i.e. using ADAS. For efficient prevention, it is necessary to make drivers understand that ADAS are not fool-proof. Therefore, we suggest not exaggerating the presentation of their performance for marketing purposes. We believe that higher safety through ADAS use can only be successful by learning how to handle ADAS safely. Further studies and training sessions are needed for a safer ADAS implementation.

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## Tables and Figures

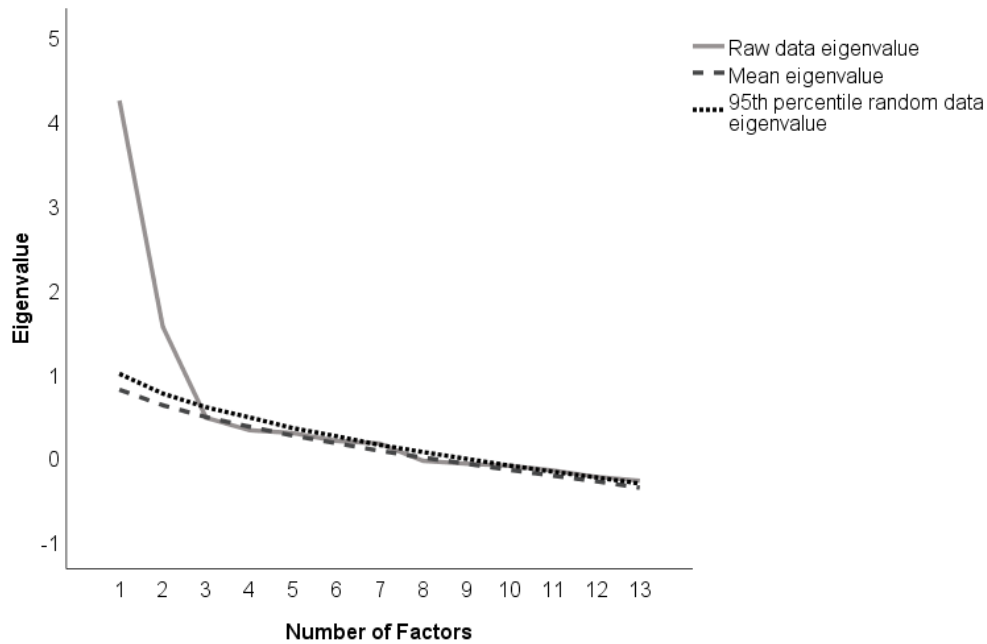


Figure 1. Parallel analysis sequence plot of the 13-item perceived accident probability scale

Table 1. Selected items for the perceived accident probability measurement scale

Items in perceived accident probability scale	Factor loading
<b>PR1</b> Not keeping the safety distance	<b>.596</b>
<b>PR2</b> Overtaking in restricted visibility conditions	<b>.738</b>
<b>PR3</b> Changing lane last minute	<b>.698</b>
<b>PR7</b> Not stopping in front of a crosswalk	<b>.629</b>
<b>PR8</b> Not looking back over one's shoulder when changing lane	<b>.478</b>
<b>PR10</b> Overtaking on the right when preceding car is too slow	<b>.580</b>
<b>PR11</b> Constantly changing lane to move on faster	<b>.755</b>
<b>PR13</b> Using cell phone handheld	<b>.625</b>

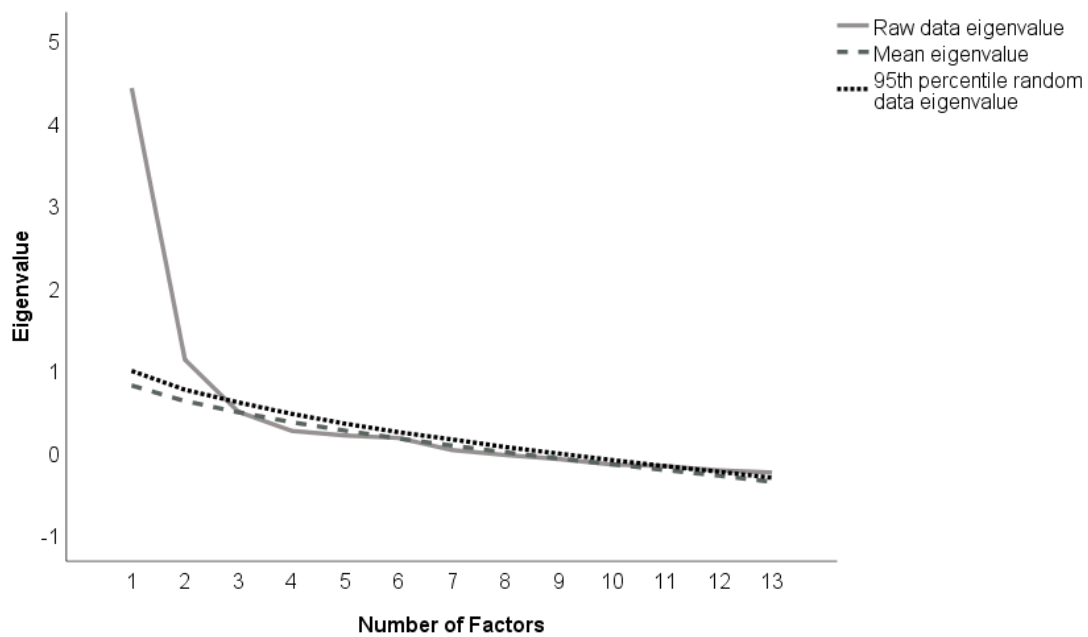


Figure 2. Parallel analysis sequence plot of the 13-item perceived risk controllability scale

Table 2. Selected items for the perceived risk controllability measurement scale

Items in perceived risk controllability scale	Factor loading
<b>CO1</b> Not keeping the safety distance	<b>.611</b>
<b>CO3</b> Changing lane last minute	<b>.722</b>
<b>CO4</b> Driving when tired	<b>.582</b>
<b>CO5</b> Exceeding the speed limit	<b>.707</b>
<b>CO6</b> Letting go of the steering wheel from time to time	<b>.569</b>
<b>CO9</b> Driving at full throttle when speed is not limited	<b>.615</b>
<b>CO10</b> Overtaking on the right when preceding car is too slow	<b>.542</b>
<b>CO11</b> Constantly changing lane to move on faster	<b>.556</b>
<b>CO12</b> Operating centre console manually	<b>.687</b>

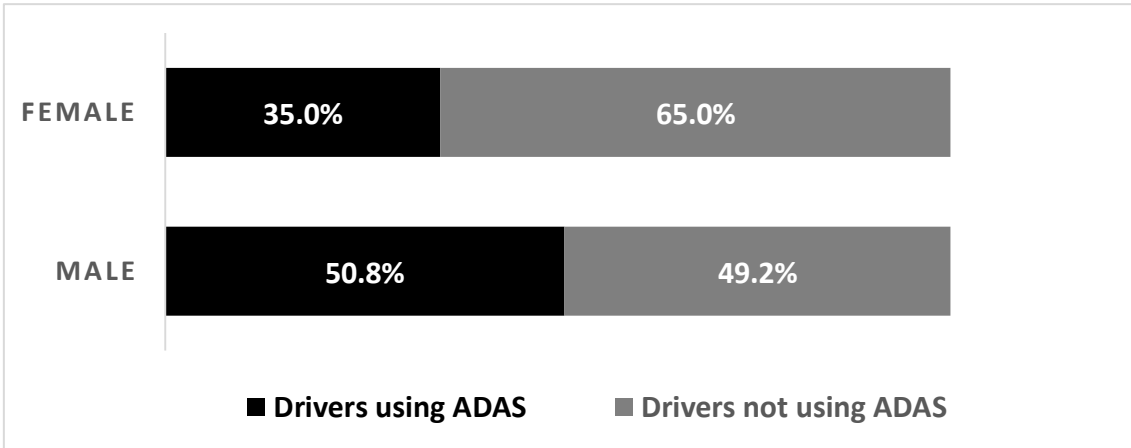


Figure 3. Study sample characteristics according to ADAS use and gender

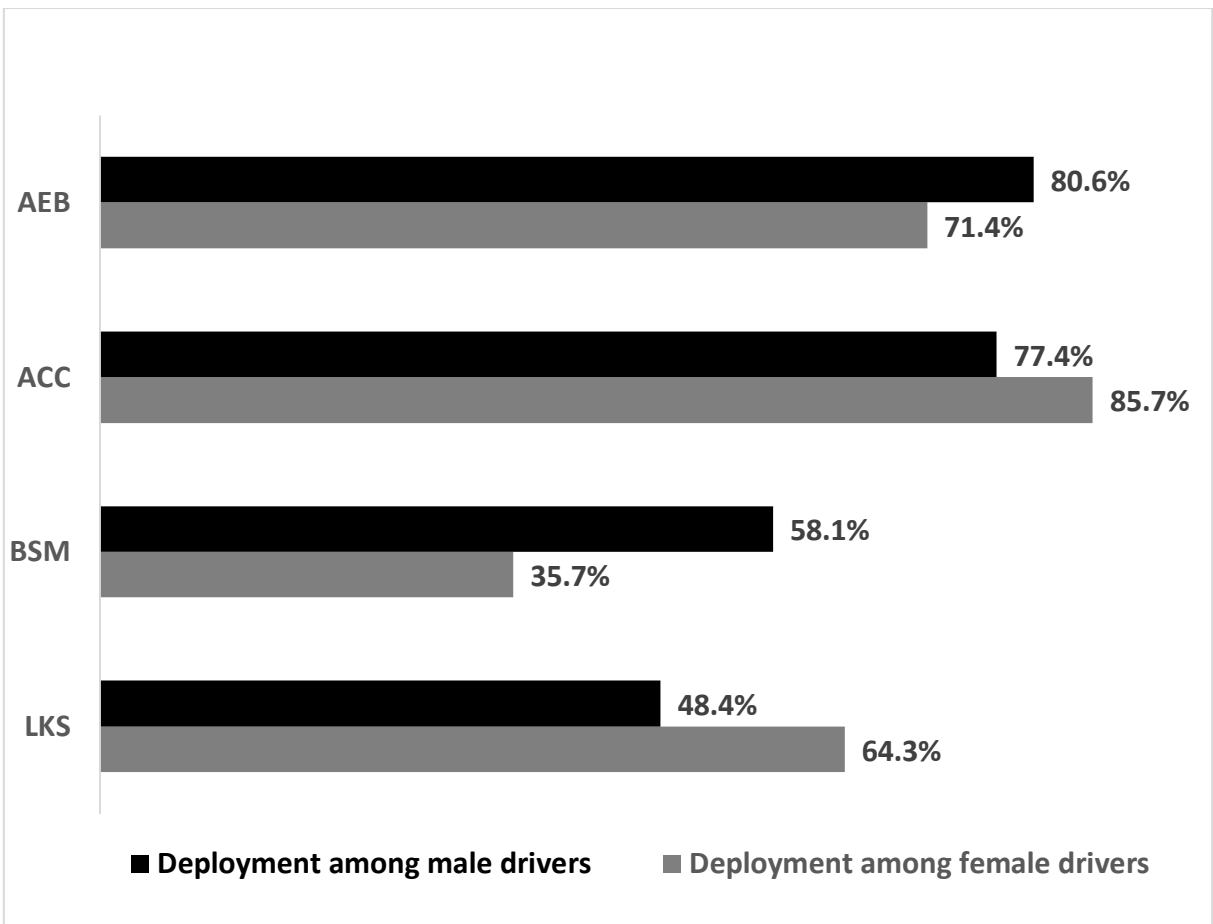


Figure 4. ADAS deployment according to gender

Table 3. Mean values and standard deviations of perceived accident probability according to ADAS and gender

Item perceived accident probability scale		ADAS		No ADAS		Male		Female	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<b>PR1</b>	Not keeping the safety distance	3.05	1.02	3.41	1.09	3.15	1.06	3.41	1.07
<b>PR2</b>	Overtaking in restricted visibility conditions	3.57	1.38	3.95	1.23	3.52	1.36	4.18	1.12
<b>PR3</b>	Changing lane last minute	3.02	1.25	3.39	1.26	2.95	1.23	3.67	1.20
<b>PR7</b>	Not stopping in front of a crosswalk	2.86	1.34	3.32	1.22	2.87	1.30	3.51	1.19
<b>PR8</b>	Not looking back over one's shoulder when changing lane	2.86	1.31	3.45	1.19	3.15	1.34	3.26	1.16
<b>PR10</b>	Overtaking on the right when preceding car is too slow	2.95	1.16	3.00	1.36	2.75	1.18	3.33	1.34
<b>PR11</b>	Constantly changing lane to move on faster	2.73	1.26	3.11	1.26	2.64	1.21	3.41	1.23
<b>PR13</b>	Using cell phone handheld	3.18	1.30	3.73	1.23	3.11	1.29	4.08	1.04
<b>Aggregated score perceived accident probability scale</b>		<b>3.03</b>	<b>0.85</b>	<b>3.42</b>	<b>0.84</b>	<b>3.02</b>	<b>0.81</b>	<b>3.59</b>	<b>0.84</b>



Table 4. Mean values and standard deviations of perceived risk controllability according to ADAS and gender

Item perceived accident probability scale		ADAS		No ADAS		Male		Female	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<b>CO1</b>	Not keeping the safety distance	3.11	1.05	2.85	1.04	2.83	1.01	3.18	1.08
<b>CO3</b>	Changing lane last minute	3.53	0.92	2.62	0.97	3.22	0.92	2.75	1.17
<b>CO4</b>	Driving when tired	2.82	0.98	2.60	1.07	2.57	0.99	2.90	1.06
<b>CO5</b>	Exceeding the speed limit	3.53	1.01	3.27	1.08	3.38	1.12	3.40	0.96
<b>CO6</b>	Letting go of the steering wheel from time to time	3.20	1.33	2.87	1.07	3.27	1.16	2.65	1.17
<b>CO9</b>	Driving at full throttle when speed is not limited	3.69	1.22	3.60	0.99	3.73	1.15	3.50	1.01
<b>CO10</b>	Overtaking on the right when preceding car is too slow	3.27	1.01	2.84	1.18	3.15	1.07	2.85	1.19
<b>CO11</b>	Constantly changing lane to move on faster	3.36	0.96	2.67	1.20	3.08	1.12	2.83	1.17
<b>CO12</b>	Operating centre console manually	3.27	1.23	2.84	0.86	3.07	1.09	2.98	1.03
<b>Aggregated score perceived accident probability scale</b>		<b>3.31</b>	<b>0.70</b>	<b>2.92</b>	<b>0.72</b>	<b>3.16</b>	<b>0.69</b>	<b>3.00</b>	<b>0.79</b>

## Measurement scales and instructions

**1 – Please find below a list of 13 types of driving behaviours that can occur while driving. Imagine yourself engaging in these driving behaviours. For each of the presented driving behaviour, please estimate the probability that an accident could happen to you personally.**

Please answer on a scale of 1 to 5.

1 = the probability that an accident will happen to you while performing the described behaviour is low

5 = the probability that an accident will happen to you while performing the described behaviour is high

Between 1 and 5, please choose the value that best matches your personal estimation. The more you approach 1, the lower you estimate the probability that an accident could happen to you while performing the described behaviour. The more you approach 5, the higher you estimate the probability that an accident could happen to you while performing the described behaviour.

1) Not keeping the safety distance	1	2	3	4	5
2) Overtaking in restricted visibility conditions	1	2	3	4	5
3) Changing lane last minute	1	2	3	4	5
4) Driving when tired	1	2	3	4	5
5) Exceeding the speed limit	1	2	3	4	5
6) Letting go of the steering wheel from time to time	1	2	3	4	5
7) Not stopping in front of a crosswalk	1	2	3	4	5
8) Not looking back over one's shoulder when changing lane	1	2	3	4	5
9) Driving at full throttle when speed is not limited	1	2	3	4	5
10) Overtaking on the right when preceding car is too slow	1	2	3	4	5
11) Constantly changing lane to move on faster	1	2	3	4	5
12) Operating centre console manually	1	2	3	4	5

13) Using cell phone handheld	1	2	3	4	5
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**2 - Please find below the same list of behaviours. Imagine yourself engaging in these driving behaviours: How do you evaluate the controllability of the driving situation? Here, controllability refers to the extent to which you personally feel able to maintain control of the driving situation without significantly increasing the risk of an accident.**

Please answer on a scale from 1 to 5.

1 = the controllability of the driving situation while performing the described behaviour is low

5 = the controllability of the driving situation while performing the described behaviour is high

Between 1 and 5, please choose the value that best matches your personal estimation. The more you approach 1, the lower you estimate the controllability of the driving situation while performing the described behaviour. The more you approach 5, the higher you estimate the controllability of the driving situation while performing the described behaviour.

1) Not keeping the safety distance	1	2	3	4	5
2) Overtaking in restricted visibility conditions	1	2	3	4	5
3) Changing lane last minute	1	2	3	4	5
4) Driving when tired	1	2	3	4	5
5) Exceeding the speed limit	1	2	3	4	5
6) Letting go of the steering wheel from time to time	1	2	3	4	5
7) Not stopping in front of a crosswalk	1	2	3	4	5
8) Not looking back over one's shoulder when changing lane	1	2	3	4	5
9) Driving at full throttle when speed is not limited	1	2	3	4	5
10) Overtaking on the right when preceding car is too slow	1	2	3	4	5
11) Constantly changing lane to move on faster	1	2	3	4	5
12) Operating centre console manually	1	2	3	4	5
13) Using cell phone handheld	1	2	3	4	5