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Pleasure in using adaptive cruise control: A questionnaire study in The Netherlands

J. C. F. de Winter [a], C. M. Gorter[b,c], W. J. Schakel[b], and B. van Arem[b]

[a]Department of BioMechanical Engineering, Delft University of Technology, Delft, The Netherlands; [b]Department of Transport & Planning, Delft University of Technology, Delft, The Netherlands; [c]Royal HaskoningDHV, Amersfoort, The Netherlands

ABSTRACT

Objective: Adaptive cruise control (ACC), a technology that allows for automated car following, is becoming increasingly prevalent. Previous surveys have shown that drivers generally regard ACC as pleasant but that they have to intervene when the ACC reaches its operational limits. The former research has been mostly concerned with specific car brands and does not fully reflect the diversity of ACC types in traffic today. The objective of the present research was to establish the determinants of pleasure in using ACC.

Methods: A 55-item online questionnaire was completed by Dutch users of diverse ACC systems.

Results: Respondents ($N = 182$) rated their ACC highly, with a mean score of 8.0 on a scale from 1 (*extraordinarily negative*) to 10 (*extraordinarily positive*) and were most pleased with ACC on high-speed roads and in low-density traffic. Moreover, the findings point to specific operational limits such as associated with cut-in situations. Pleasure was greater for the types of ACC that are able to decelerate to a full stop, according to 48% of our sample. An analysis of the free-response items indicated that respondents who were displeased with ACC mentioned its occasional clumsiness and the dangerous situations it may evoke, whereas those who were pleased with ACC valued the complementarity of human and machine and emphasized the roles of responsibility and experience in using ACC.

Conclusion: Pleasure in using ACC is a function of both technological advances and human factors.

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Introduction

Adaptive cruise control (ACC) is becoming increasingly common on the roads. European market research indicates that in the years 2011 and 2013, respectively, 1.7 and 3.2% of newly sold cars were equipped with ACC, with Germany being the frontrunner (3.7 and 6.8%, respectively; Öörni 2016). A recent survey among a representative sample of U.S. drivers showed that 14% of respondents had ACC in their vehicle (McDonald et al. 2016). Considering the growing prevalence of ACC, it is of paramount importance to examine users' attitudes toward this technology. Questionnaires are a powerful tool for examining a person's beliefs, many of which may be too private to be detected by means of observational driving studies.

ACC can be expected to enhance comfort because it removes the need for the driver to respond to moment-to-moment fluctuations in headway to the car in front. Experimental studies have confirmed that ACC reduces self-reported workload compared to manual driving (e.g., Bianchi Piccinini et al. 2014; de Winter et al. 2014; Ma 2006; Saffarian et al. 2012; Young and Stanton 2007), and various surveys have shown that ACC users are positive about the comfort that this technology brings (Cicchino and McCartt 2015; Eichelberger and McCartt 2014, 2016; Jenness et al. 2008; Llaneras 2006; Sanchez et al. 2012; Van Twuijver and Pol 2004). For example, telephone interviews with 183 owners of Toyota vehicles found that about 70% of the respondents believed that ACC makes driving less stressful (Eichelberger and McCartt 2016).

ACC is highly accepted, but there are some safety-related concerns that may negatively impact users' appreciation of ACC. On the one hand, ACC can be expected to increase safety because it helps maintain a constant headway, and various field studies have indeed shown more consistent car following at greater mean headway than in manual driving (Alkim et al. 2007; Kessler et al. 2012; Pauwelussen and Feenstra 2010; Pauwelussen and Minderhoud 2008; Rakha et al. 2001). On the other hand, ACC introduces new responsibilities with respect to manual driving. Drivers have to be alert and intervene in case the ACC fails to detect a road obstacle, when it reaches its functional limits such as when a lead vehicle brakes hard, or when it otherwise acts inappropriately given the traffic conditions. A number of driving simulator studies have shown that participants driving with ACC sometimes failed to act timely when a sudden intervention was required (Lee et al. 2007; Rudin-Brown and Parker 2004; Stanton et al. 1997). Moreover, a recent field operational test showed that when ACC is active, drivers are more likely to engage in nondriving tasks (Kessler et al. 2012), which may exacerbate risks when drivers suddenly have to reclaim manual control.

A focus group study among ACC users in Sweden shed light on the types of events that require manual intervention. Participants expressed concerns that the ACC may brake hard when

CONTACT J. C. F. de Winter j.c.f.dewinter@tudelft.nl Department of BioMechanical Engineering, Delft University of Technology, Delft, The Netherlands.
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another road user cuts in between the ACC-equipped host vehicle and the vehicle ahead. The focus group also revealed that unintended accelerations can occur when the forward-facing sensors lose track of the lead vehicle on curvy roads or roundabouts. Furthermore, it was reported that ACC may malfunction in heavy weather conditions such as snowfall, and may inadvertently detect and respond to a vehicle in an adjacent lane (Strand et al. 2011). Similarly, a survey among 131 Volvo ACC users showed that the most frequently mentioned system limitations were (1) loss of radar contact with the lead vehicle in sharp curves or roundabouts, (2) loss of contact or close estimated headway when being overtaken by another car, (3) hard braking of the vehicle in front (requiring manual intervention), and (4) locking onto (large) vehicles in an adjacent lane, resulting in a braking action by the ACC (Larsson 2012). These authors also found that within less than a year of driving with ACC, 31 of 131 respondents had experienced a mode error where it had occurred to them at least once that they had forgotten whether the system was active or inactive (Larsson 2012). In summary, with ACC the driver has to monitor both the outside environment and the ACC status to see whether it still functions as it should. Arguably, the complexity of the driving task is higher for ACC driving than for manual driving or, as pointed out by Banks et al. (2014), driving with automation is "feet-free," not "mind-free."

Whether or not a driver is overly trusting in the capabilities of the ACC is regarded as an important determinant of ACC safety (e.g., Dickie and Boyle 2009; Strand et al. 2011). Drivers' trust in ACC has been shown to depend on whether the driver has been explained what types of objects it does and does not detect (Beggiato and Krems 2013). Larsson (2012) showed that the more experienced the driver is with ACC, the more likely he or she is to declare that the ACC has limitations, which suggests that drivers develop a mental model of the ACC over time. Similarly, an on-road study with 15 drivers showed that self-reported knowledge about how to operate ACC increased across 10 drives spread out over a 2-month period (Beggiato et al. 2015). Given the critical roles of training and experience, it is somewhat disconcerting that a recent questionnaire study found that 29% of ACC drivers were self-taught (i.e., not having read the owner's manual and not having received a demonstration from a dealer; Bato and Boyle 2011).

ACC was first introduced on the market in the late 1990s and has undergone various refinements over the years (Bengler et al. 2014). Whereas earlier ACCs only released the throttle ("coasting") when a lead vehicle slowed down (Fancher et al. 1998), modern ACCs apply the brakes when the lead car decelerates hard. Moreover, various car manufacturers have now released ACC systems that can function over the full speed range. Early surveys among representative ACC users were conducted when full speed range ACC did not yet exist (Jenness et al. 2008; Llaneras 2006), and there is little research that examined pleasure in using ACC for different degrees of technological capability. Recent research surveyed ACC users of a specific brand by acquiring contact addresses via dealers or sales departments (e.g., Eichelberger and McCartt 2016). We used a different approach by sending out invitations to a large number of potential ACC users with the help of a large Dutch traveler's association in order to survey ACC users of multiple car models. The aim of the present study was to investigate self-reported pleasure and driving behaviors of present-day ACC users. Furthermore, we assessed statistical associations between personal characteristics (age, driving experience, driving style), availability of full speed range ACC, and pleasure in using ACC.

Methods

Distribution of the questionnaire

In March 2015, a news item on ACC together with an invitation to complete an online questionnaire was published on the website of a traveler's association in The Netherlands (Royal Dutch Touring Club ANWB; www.anwb.nl/auto). To bring the research under the attention of a large audience, the news item was also mentioned in a periodic newsletter of the ANWB, sent to approximately 100,000 e-mail addresses. In addition, the social media accounts (LinkedIn, Facebook, and Twitter) of the Department of Transport and Planning of the faculty of Civil Engineering of the TU Delft and of a large Dutch engineering consulting company (Royal HaskoningDHV) were used to bring the questionnaire under the attention of potential ACC users. Four 25 Euro vouchers of a tourist information office were allotted. All data were collected between March 9 and May 18, 2015.

Questionnaire content

The opening page of the questionnaire stated that the questionnaire concerned the use of adaptive cruise control, an optional system in vehicles that is able to detect and respond to the car in front. It further stated that the questionnaire was fully anonymous and would take about 10 min to complete.

Demographics, driving experience, ACC characteristics, and ACC use

The questionnaire asked for personal details, namely, (Q1) gender, (Q2) age, (Q3) being in possession of a driver's license, (Q4) number of years in possession of a driver's license, and (Q5) yearly mileage. The questionnaire also asked (Q6) whether respondents were experienced with ACC, with *experience* being defined as owning an ACC-equipped car or driving an ACC-equipped car on at least a weekly basis. The full questionnaire was accessible to respondents who answered yes to this last question. A number of questions followed about the use of ACC and the type of ACC the respondents used. Specifically, the questionnaire asked about (Q7) car brand, (Q8) manual versus automatic transmission, (Q9) whether their ACC deactivates below a certain speed, (Q10) whether their ACC allows for adjusting the following distance, (Q11) whether the ACC-equipped car they use is their own, (Q12) whether they use the car for private or business purposes, (Q13–Q15) how frequently they use ACC (years of experience, weekly mileage, use in the past 6 months), (Q16) whether respondents had deliberately chosen ACC as an option in their car or not (e.g., because the ACC-equipped car is not their own), (Q17) whether respondents had been informed about the operation of ACC (e.g., by a car dealer or by reading the owner's manual), and (Q18) whether the respondents are aware of the limitations and risks of ACC.

Driving pleasure in different environmental conditions

Next, questions were presented about the degree of pleasantness of using ACC (Q19) on roads in the built-up area, (Q20) on provincial roads outside the built-up area, (Q21) on expressways, and (Q22) on highways. The degree of pleasantness of driving on the highway was also asked regarding situations when there is (Q23) little to no traffic, (Q24) average traffic, (Q25) a lot of traffic, and (Q26) heavy traffic. Q19–Q26 were asked on a 5-point Likert scale from *very unpleasant* to *very pleasant*. Moreover, near the end of the questionnaire, respondents were asked to (Q45) give an overall rating from 1 (*extraordinarily negative*) to 10 (*extraordinarily positive*) to the ACC they are experienced with. In an additional multiple-choice question (Q46), respondents were asked to indicate whether they would recommend ACC to another person on a 5-point scale from *strongly disagree* to *strongly agree*.

Safety-related behaviors

Respondents were asked (Q27) whether ACC reduces their effort to drive a car, (Q28) whether ACC reduces their alertness during driving, and (Q29) whether they are more likely to engage in nondriving activities when ACC is enabled. Next, 5 safety-related questions were asked regarding the use of ACC compared to not using ACC. Specifically, respondents indicated (Q30) whether ACC reduces their risk of head–tail collisions, (Q31) whether ACC reduces their risk of unsafe situations, (Q32) whether ACC reduces their frequency of speeding, (Q33) whether ACC increases response times in case manual intervention is needed, and (Q34) whether they would prefer that ACC only gave a notification and/or auditory signal instead of actively intervening. Q27–Q34 were on a 7-point scale from *strongly disagree* to *strongly agree*.

Events that occur while driving with ACC

Six questions were presented about the frequency of events that may occur when ACC is enabled. Respondents were asked on a 7-point scale from *absolutely never* to *always* (Q35) how often they override their ACC by means of the throttle because ACC adopts a too large following distance; (Q36) how often a car cuts in front as a result of which the ACC brakes hard; (Q37) how often they apply extra throttle in order to overtake another car; (Q38) how often it happens that the ACC loses track of the car in front in a sharp curve, resulting in unintended acceleration; (Q39) how often their ACC unexpectedly disengages; and (Q40) how often their ACC suddenly brakes or accelerates when they did not expect this to happen.

Traffic flow–related behaviors

Questions related to behaviors that may affect traffic flow were asked on a 7-point scale from *strongly disagree* to *strongly agree*. Specifically, respondents indicated whether their use of ACC compared to not using ACC results in (Q41) more uniform driving, (Q42) greater following distance with respect to the vehicle in front, (Q43) a reduction in lane changes, and (Q44) increased driving in the right lane.

Driving style

Nine questions followed about the respondents' driving style regardless of ACC use. Respondents were asked to indicate their driving style on a dimension from (Q47) slow to fast, (Q48) careful to careless, (Q49) tolerant to intolerant, and (Q50) indecisive to decisive. Respondents further indicated on a 7-point scale from *absolutely never* to *always* (Q51) how often they drive so close to the car in front that it would be difficult to brake safely in case of an emergency, (Q52) how often they disobey the speed limit on the highway, (Q53) how often they receive fines for traffic violations, (Q54) how often they get annoyed with other road users, and (Q55) how often they engage in other activities behind the wheel such as calling, using a smartphone, or smoking.

Free-response items

The questionnaire included a number of textboxes in which respondents could clarify their answers. Specifically, after Q22, Q26, Q29, Q34, and Q44, there was a textbox accompanied by the statement "Space for an optional explanation." After Q40, there was a textbox: "Are there other situations which you experience/have experienced while using ACC and which you consider as unsafe or unpleasant? Please also indicate how often this situation occurs"; after Q45 there was a textbox: "Could you please indicate why you gave this rating?"; and after Q46 there was a textbox: "Do you have other experiences, remarks, or tips regarding the design and the use of adaptive cruise control?"

Analysis of the responses

The inclusion criteria for the analysis were as follows: at least 18 years old (Q2), having a driver's license (Q3), having used ACC in the past 6 months (Q15), and having completed all items of the questionnaire. For Q46, a median substitution was performed for the 2 respondents who answered "I don't know" to this question. Descriptive statistics (frequency counts, means, and standard deviations) were calculated per questionnaire item. Associations between driving style, ACC-related pleasure, driver characteristics, and the availability of full speed range ACC were assessed by means of Spearman's rank order correlations (ρ). Moreover, the answers to the free-response items were analyzed by the first author for communalities and were counterchecked by a second analyst.

Results

Descriptive statistics of the respondents

An overview of the characteristics of the 182 respondents is provided in Table A1 (see online supplement). The sample generally consisted of male drivers (96%; Q1) with over 20 years of driving experience (90%; Q4). A large proportion of respondents (48% after excluding respondents who stated that they do not know) indicated they had an ACC that is able to come to a full stop (Q9), and 22% of respondents indicated that the car had a manual transmission (Q8). Respondents selected 17 different car brands (Q7), the most common ones being Volvo (34 respondents), Toyota (26), Volkswagen (25), BMW (21), Peugeot (16), Audi (15), Mercedes (9), and Mitsubishi (8).

Most respondents indicated that the ACC-equipped car was their own (64%; Q11) and that they had deliberately chosen to have ACC in the car (70%; Q16). The majority of respondents (52%) used the car for both private and business purposes, whereas 5% used the car for business only (Q12). Only 32% of respondents reported more than 2 years of experience with ACC (Q13), yet mileages were high, with only 16% reporting a weekly mileage below 200 km (Q14). The majority indicated having been extensively informed about ACC (46%; Q17) and being fully aware of its risks and limitations (66%; Q18).

Data quality checks and additional filtering

We performed validation checks based on the reported car brand (Q7) and ACC/vehicle characteristics (Q8–Q10). First, we confirmed that ACC is available for each of the 17 brands reported in Q7. Second, of the 62 respondents who reported a brand that did not feature full speed range ACC as of 2015 (i.e., Citroën, Ford, Honda, Jaguar, Mazda, Peugeot, Toyota), 2 respondents mistakenly indicated that their ACC is able to come to a full stop (Q9). For these 2 respondents, the response to Q9 was omitted. Third, 2 of 78 respondents who indicated that they had full range ACC (Q9) mistakenly reported that they had a manual transmission (Q8) and therefore their responses to Q8 and Q9 were omitted. Fourth, 6 respondents indicated that their ACC does not allow for adjusting following distance (Q10), though contemporary ACCs all have this feature (but see an early questionnaire showing that about 7% of respondents indicated that their ACC does not allow changing following distance; Jenness et al. 2008). For these 6 respondents the responses to Q10 were omitted. Note that 4 of these 6 respondents referred to aspects of ACC functionality in their free-response answers, making it unlikely that they had confused conventional cruise control for ACC.

Driving pleasure in different environmental conditions

The results regarding driving pleasure as a function of the road conditions are shown in Table 1. The faster the road type and the lighter the traffic density, the more pleasant ACC was considered to be. On a scale from 1 (*extraordinarily negative*) to 10 (*extraordinarily positive*), respondents rated their ACC with a mean of 8.0 (SD = 1.58; Q45). Respondents highly agreed with the idea of recommending ACC to others (Q46), with a mean of 4.19 (SD = 0.99) on a scale from 1 (*strongly disagree*) to 5 (*strongly agree*), with 86 and 63 respondents selecting *strongly agree* and *agree*, respectively. Thus, respondents were positive toward ACC, especially in light traffic and on high-speed roads.

Table 1. Results regarding pleasure in different traffic conditions.[a]

	M	SD
Q19. On roads in a built-up area	2.86	1.23
Q20. On provincial roads outside of built-up areas	4.04	1.02
Q21. On expressways	4.30	0.96
Q22. On highways	4.36	1.00
Q23. Little to no traffic—No interaction with other vehicles	4.51	0.85
Q24. Average traffic—Occasional interaction with other vehicles	4.29	0.89
Q25. A lot of traffic—(Almost) continuous interaction with other vehicles	3.34	1.25
Q26. Heavy traffic—Slowly driving traffic or congestion	3.21	1.50

[a] 1 = *Very unpleasant*, 2 = *unpleasant*, 3 = *neutral*, 4 = *pleasant*, 5 = *very pleasant*. A header above Q23–Q26 stated that these questions applied to the highway.

Table 2. Results regarding safety with ACC on compared to ACC off.[a]

	M	SD
Q27. If I have ACC turned on, driving costs me less effort	5.49	1.50
Q28. If I have ACC turned on, I have to pay less attention in traffic	3.05	1.69
Q29. If I have ACC turned on, I perform more activities while driving (calling, using a smartphone, etc.)	2.29	1.53
Q30. If I have ACC turned on, I have less risk of head–tail collisions	5.54	1.44
Q31. If I have ACC turned on, I less often end up in unsafe situations	4.86	1.50
Q32. If I have ACC turned on, I less often drive faster than the speed limit	5.09	1.81
Q33. If I have ACC turned on, I require more time to brake or to apply an additional steering action, if this is needed	2.91	1.59
Q34. I would rather have that ACC only gave a notification and/or auditory signal instead of actively intervening	2.20	1.45

[a] 1 = *Strongly disagree*, 2 = *disagree*, 3 = *somewhat disagree*, 4 = *neutral*, 5 = *somewhat agree*, 6 = *agree*, 7 = *strongly agree*.

Safety-related behaviors

The results for the safety-related questions are shown in Table 2. Respondents somewhat agreed with the statements that ACC helps to reduce effort (Q27), reduce speeding (Q32), prevent head–tail collisions (Q30), and prevent ending up in unsafe situations (Q31) compared to driving without ACC. At the same time, respondents somewhat disagreed with the statements that ACC permits them to pay less attention in traffic (Q28) and that ACC results in delayed reactions compared to driving without ACC (Q33). Moreover, respondents disagreed with the statement that they engage in more activities behind the wheel if ACC is engaged (Q29).

Events that occur while driving with ACC

The results regarding ACC-related events in Table 3 show that respondents sometimes have to overrule the ACC in order to reduce a gap (Q35) or to overtake another car (Q37). Similarly, respondents indicated that it sometimes happens that their car brakes hard because of a vehicle cutting in (Q36). More rarely, the ACC showed unexpected disengagement (Q39) or intervention (Q40). Unexpected accelerations because the ACC loses track of the car in front were reported to occur with rare to moderate frequency (Q38).

Traffic flow–related behaviors

Results in Table 4 show that respondents on average somewhat agreed with the statement that ACC causes them to drive more

Table 3. Results regarding the frequency of events that occur when driving with ACC.[a]

	M	SD
Q35. You apply additional throttle in order to reduce a large gap with the vehicle in front because the ACC adopts a too large headway	2.92	1.38
Q36. A car cuts in between you and the vehicle in front and your car reacts by hard braking	3.35	1.34
Q37. You apply additional throttle to overtake another car because your car would otherwise brake in response to this car	3.60	1.43
Q38. In a sharp curve the ACC of your car loses sight of the car in front, so your car accelerates unexpectedly	2.59	1.37
Q39. ACC suddenly disengages when you did not expect this to happen	1.65	0.85
Q40. ACC suddenly brakes or accelerates when you did not expect this to happen	2.04	1.05

[a]1 = *Absolutely never*, 2 = *almost never*, 3 = *sometimes*, 4 = *neutral*, 5 = *often*, 6 = *almost always*, 7 = *always*.

uniformly, with fewer accelerations and decelerations (Q41). Similarly, respondents reported that they drive with greater following distance (Q42) and make a smaller number of lane changes (Q43) with ACC compared to without.

Relationships with ACC pleasantness and risky driving style

Data reduction was performed, because survey items are typically correlated with each other and thereby exhibit a degree of redundancy. Specifically, the 38 items that were concerned with the respondents' attitudes toward ACC or with driving style (Q18–Q55) were reduced into a smaller number of components by means of principal component analysis after rank transformation of the individual variables (Conover and Iman 1981). Based on a visual inspection of the eigenvalues of the correlation matrix (scree plot) and by interpretation of the varimax-rotated component loadings, we decided to retain 2 components. The component scores were calculated according to the least scores regression method and had a mean of 0 and standard deviation of 1.

The first component, explaining 21.7% of the variance, was interpreted as *ACC pleasantness*. The strongest loadings (>0.75) on this component occurred for pleasantness on expressways (Q21; loading = 0.79), pleasantness in average traffic conditions (Q24; loading = 0.76), overall rating assigned to ACC (Q45; loading = 0.84), and whether respondents would recommend ACC to another person (Q46; loading = 0.85).

Table 4. Results regarding traffic flow–related behaviors with ACC on compared to ACC off.[a]

	M	SD
Q41. If I have ACC turned on, I drive more uniformly (meaning that I have to brake or accelerate less often)	5.28	1.62
Q42. If I have ACC turned on, I keep a larger distance to the car in front	5.65	1.25
Q43. If I have ACC turned on, I change lanes on the highway less often	4.61	1.58
Q44. If I have ACC turned on, I drive in the right lane on the highway more often	4.03	1.65

[a]1 = *Strongly disagree*, 2 = *disagree*, 3 = *somewhat disagree*, 4 = *neutral*, 5 = *somewhat agree*, 6 = *agree*, 7 = *strongly agree*.

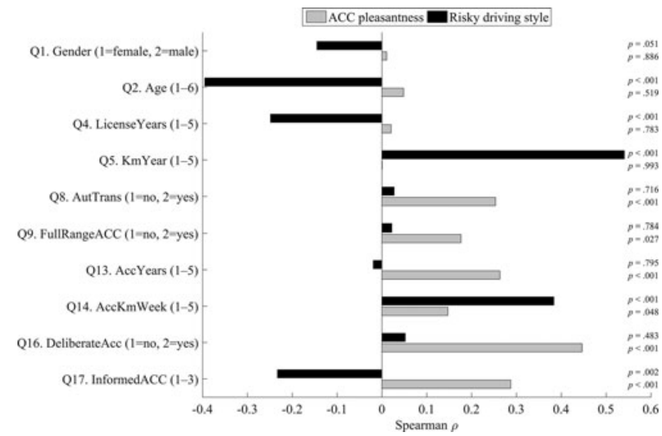

Figure 1. Spearman's rank order correlation coefficients between component scores and driver/ACC parameters. Also shown are *P* values for the null hypothesis that the correlation is 0 in the population.

The second component, explaining 8.9% of the variance, was interpreted as *risky driving style* with the strongest loadings (>0.50) on "If I have ACC turned on, I have to pay less attention in traffic" (Q28; loading = 0.63), "If I have ACC turned on, I perform more activities while driving" (Q29; loading = 0.66), "Applying additional throttle in order to reduce a large gap with the vehicle in front because the ACC adopts a too large following distance" (Q35; loading = 0.54), and performing nondriving activities behind the wheel (Q55; loading = 0.65).

Spearman rank order correlations were calculated between respondents' ACC pleasantness scores and risky driving style scores on the one hand and the personal characteristics and ACC features that are expressed on a binary or ordinal scale on the other (Figure 1). ACC was considered more pleasant when the respondent's car had an automatic transmission (Q8) or full speed range ACC (Q9), when respondents had more experience with ACC (Q13 and Q14), when respondents had deliberately chosen to have ACC in their car (Q16), and when respondents had been informed about the working mechanisms of ACC (Q17).

An item-based analysis showed that ACC that does not deactivate below a set speed limit (Q9) was particularly highly regarded when driving in congestion (Q26). Specifically, on the 5-point scale from 1 (*very unpleasant*) to 5 (*very pleasant*), the mean on Q26 was 4.08 (SD = 1.22) for full speed range ACC versus 2.90 (SD = 1.39) for regular ACC ($t = 5.59$, df = 155, $p < .001$). Moreover, respondents using full speed range ACC were less likely to report that ACC suddenly disengages (Q39), with means of 1.36 (SD = 0.65) versus 1.90 (SD = 0.93) on a scale from 1 (*absolutely never*) to 7 (*always*; $t = -4.15$, df = 155, $p < .001$).

Respondents who drove more kilometers per year (Q5) or per week with ACC (Q14) and who were younger (Q2 and Q4) scored higher on the risky driving style component. Furthermore, respondents who had been more informed about ACC (Q17) had a lower risky driving style score (Figure 1). Furthermore, females tended to have a higher risky driving style than males, although this finding has to be interpreted cautiously because there were only 8 females among the 182 respondents.

An analysis of car brands with 10 or more respondents revealed the following mean ACC pleasantness scores and 95% confidence intervals: BMW (M = 0.68, 95% confidence interval [CI], [0.30, 1.06]), Toyota (M = 0.39, 95% CI, [−0.02, 0.81]), Audi (M = 0.28, 95% CI, [−0.14, 0.69]), Volvo (M = 0.12, 95% CI, [−0.13, 0.37]), Volkswagen (M = 0.11, 95% CI, [−0.29, 0.52]), and Peugeot (M = −0.67, 95% CI, [−1.13, −0.21]). The relatively low scores for Peugeot may be because this is the only of these 6 brands with an ACC that does not apply the brakes. Instead, it releases the throttle (engine braking or coasting), which means that the car loses speed slowly (Peugeot 2014).

Textual responses: Why do respondents find ACC pleasant or unpleasant?

In order to acquire more detailed information on why some respondents were particularly pleased or displeased with ACC, we examined the free-response items. The responses of the 20 participants with the lowest ACC pleasantness scores and the 20 participants with the highest ACC pleasantness scores were selected for this in-depth investigation.

Analysis of free-response items of respondents who found ACC unpleasant

An analysis of the textual responses of the 20 respondents with the lowest ACC pleasantness scores was conducted. Several respondents mentioned that ACC sometimes brakes unnecessarily. One respondent mentioned that a feeling of panic may occur when the ACC intervenes by braking hard after another car cuts in front, and another respondent mentioned that it is stressful to anticipate the ACC's braking interventions. Moreover, a respondent described a situation where a car behind almost collided with his car, because his ACC braked hard after a car had cut in front, and another respondent described a situation in which his car suddenly braked on the highway when there was no car in front whatsoever. A respondent also stated that the hard braking of his ACC must be highly unpleasant for cars driving behind.

Several respondents were concerned about the restless behavior of their ACC. For example, when a car in front changes lanes, the ACC suddenly accelerates and then decelerates when arriving at a new vehicle in front. A respondent reported that it is uneconomical and unpleasant that ACC makes him dependent on the poor driving skills of the car in front. Another respondent mentioned that ACC may cause unintended overtaking on the right.

Respondents also mentioned that ACC is "blind" in curves, may disengage itself too quickly, or may react to irrelevant obstacles. Several respondents disliked the ACC's conservative headway and its sluggish behavior when overtaking another car; some respondents indicated that many gas pedal inputs are needed in order to proceed in traffic. One respondent expressed annoyance at the beeping sound that occurs when the lead car disappears from the radar view. Positive remarks were made as well; it was mentioned that ACC can be relaxing and keeps an eye on the road, yet respondents also mentioned that further developments are needed. A number of respondents indicated that they prefer to make use of conventional cruise control or a speed-limiting functionality rather than ACC.

Analysis of free-response items of respondents who found ACC pleasant

The 20 respondents with the highest ACC pleasantness scores reported the following. Several respondents indicated that the ACC behaves in a predictable manner and that it complements or surpasses human ability. For example, one respondent indicated that ACC is advantageous when driving in heavy fog, and another respondent mentioned that ACC outperforms human drivers when it comes to remaining alert and responding quickly to traffic events.

Two respondents mentioned that ACC supports safe (hand-free) talking on the phone. Respondents indicated that ACC reduces effort and brings calmness, enjoyment, subtlety, and an extra layer of security in overall driving behavior. Moreover, it was mentioned that ACC reduces fuel consumption.

Respondents indicated that their ACC may act inappropriately given the traffic conditions. For example, it was mentioned that ACC may simply accelerate up to the set speed when exiting a traffic jam, that it may malfunction during heavy rain, that it occasionally provides a false notification or unneeded braking intervention, and that it may not work at low speeds or at very high speeds. However, respondents indicated that the driver has to be alert and remains responsible for safe driving. Moreover, it was mentioned that it requires trust, experience, and knowledge of the characteristics of the specific ACC in order to use it appropriately and to be able to anticipate when it will reach its operational limits. Several respondents mentioned that the quality of ACC differs between car brands and that the newer ACCs perform better and are more fine-tuned than older versions. One respondent reported that his passengers were consistently amazed after he disclosed that he was not driving himself but that the automation did.

Discussion

Pleasure and risk-related behaviors among ACC users

The aim of this study was to measure pleasure and risk-related behaviors among a sample of Dutch ACC users. Consistent with previous survey research on specific car brands (e.g., Eichelberger and McCartt 2016), the results indicated that respondents were pleased with their ACC systems, with a mean rating of 8.0 on a scale from 1 to 10, and 82% of respondents agreed or strongly agreed with the statement, "I would recommend ACC to another person." ACC was particularly well appreciated on motorways and expressways and in traffic of low density (Table 1).

Respondents believed that ACC helps them drive more safely, especially with respect to preventing head–tail collisions (Table 2), and that ACC improves aspects of traffic flow (Table 4), which is consistent with field tests of ACC (e.g., Alkim et al. 2007; Kessler et al. 2012). The observation that ACC reduces the number of lane changes (Q43) is consistent with a past survey on ACC use in the United States (Jenness et al. 2008).

It is interesting that respondents, on average, *believed* that ACC does not permit them to pay less attention in traffic (Q28) or to engage in nondriving activities (Q29) despite the fact that ACC takes over the car-following task. However, some respondents disclosed that ACC helps them perform otherwise unsafe activities such as using a phone or driving in fog. Whether ACC improves safety in fog is questionable because driving at a large headway (as ACC tends to do) means that the lead car is difficult to see. Manual drivers in fog engage in the opposite behavior: they tend to adopt short headways to keep the lead car in sight (Boer et al. 2008; Saffarian et al. 2012). In other words, driving in fog with ACC could enhance safety because the ACC's radar functions as an extra pair of eyes but only if the driver remains attentive in order to intervene if necessary.

Although rare to medium in frequency, respondents experienced a variety of ACC-induced events that disrupted the driving task or required manual intervention (Table 3). The analysis of the free-response items showed that respondents who were displeased with ACC were particularly critical toward the behavior of ACC during cut-in situations and other types of dangerous events evoked by ACC. Respondents who were pleased with ACC also experienced functional limitations of various kinds but simultaneously appreciated its capacities and indicated that they trusted the ACC and that they have learned the ins and outs of the system in order to anticipate when manual intervention is needed.

In summary, it appears that ACC is regarded as a system that offers comfort but demands alertness and experience for appropriate reliance. These observations are in line with Banks et al. (2014), who emphasized that when using ACC the driver is expected to be an active monitor, and with longitudinal studies showing that driving experience enhances mental models and trust in ACC (Beggiato et al. 2015; Weinberger et al. 2001). According to the analysis of free-response items, ACC-induced events may occasionally be annoying or even dangerous, and so whether ACC improves safety (as respondents seem to believe; see Q31) remains unknown. Arguably, an appropriate human–machine interface may resolve some of these issues and help drivers anticipate critical events (Seppelt and Lee 2007; Stanton et al. 2011) compared to beeps, which may disturb drivers (Biondi et al. 2014).

Correlates of ACC pleasantness and risky driving style

The correlational analysis showed that the degree of pleasure in using ACC is moderated by its technological capabilities (Figure 1): ACC that is able to come to a full stop was found to be significantly more pleasant in congested traffic (Q29) and to less often disengage unexpectedly (Q36). Future generation ACCs, such as cooperative adaptive cruise control, may provide further advantages to the driver such as safe and stable following at close headways by virtue of vehicle-to-vehicle or infrastructure-to-vehicle communication (Milanés et al. 2014; Schakel et al. 2010). With the aim of improving the "hedonic quality of the ACC," Totzke et al. (2008, p. 161) introduced 2 buttons on the steering wheel that allowed for a temporarily stronger acceleration and deceleration, respectively. Their driving simulator study showed that pleasure in driving with these buttons was higher than during conventional ACC driving and that the ACC behaved more human-like during overtaking. Similar override features may be helpful to overcome the limitations of ACC in dynamic situations and enhance driving pleasure.

The results demonstrate that driving with ACC is characterized by various events that require human intervention, indicating that human input remains crucial or, as Bainbridge (1987) famously put it, "The more advanced a control system is, so the more crucial may be the contribution of the human operator" (p. 271). Drivers with a risky driving style were generally younger and more likely to drive and use ACC (Figure 1), which is consistent with previous research showing that the use of ACC (e.g., the headway set by the driver) is a function of the driver's age and driving style (Cicchino and McCartt 2015; Jenness et al. 2008; Wu and Boyle 2015; Xiong et al. 2012). Moreover, these results are coherent with previous questionnaire and observational research in manual driving showing that young drivers are more likely to commit traffic violations than older drivers (de Winter et al. 2015; Martinussen et al. 2014; Parker et al. 1995).

Risky driving behaviors of diverse types were correlated with each other. For example, 2 causally unrelated items—applying additional throttle in order to reduce a large gap when using ACC (Q35) and performing nondriving activities behind the wheel during manual driving (Q55)—both loaded on the risky driving style component (loadings of 0.54 and 0.65, respectively). This suggests that risky driving is a persistent and personal factor and that ACC that replaces components of driving skill does not repress risky driving or, in simpler words, if a person drives in a risky manner, he is likely to do so both in manual driving and in automated driving.

Limitations and recommendations

A limitation of any self-reported questionnaire is common method bias, including item-characteristic effects (e.g., the repeated use of the same scale type/anchors) and rater effects such as social desirability (Podsakoff et al. 2003). Social desirability may especially be at play when it comes to disclosing illegal activities such as using a mobile phone while driving or when indicating one's risk awareness (e.g., Q18). However, anonymity, as was adopted in the present survey, may resolve some of these concerns (Dodou and de Winter 2014). For example, Lajunen and Summala (2003) found that in a public setting (i.e., when applying for a driving instructor training course as part of the entrance examination), not one of about 50 respondents admitted having been driving when over the legal blood alcohol limit, whereas 23% confessed this illegal behavior in a private setting in which confidentiality was stressed. Nonetheless, whether the self-reported driving style reflects objective driving style remains uncertain. It is possible that the more competent or more experienced drivers engaged in more risky behaviors because they are more skilled in driving and in recognizing the limitations of ACC, which would be consistent with the risk homeostasis theory (Wilde 1988).

Another limitation was that respondents were relatively old (42% of respondents were older than 60) and predominantly male (96%). Previous ACC survey research yielded similar patterns regarding the demographic characteristics (e.g., Eichelberger and McCartt 2016: 69% male, 50% older than 60 years; Llaneras 2006: 67% male, 47% older than 60; Larsson 2012: 82%

male; Strand et al. 2011: 94% male). We suspect that (1) ACC is generally regarded as a luxury product that is more likely to be bought by male persons with a high income, (2) the membership of the traveler's association consists of older males, and (3) older males are more likely to read a newsletter and volunteer to participate in a survey (see also ANWB 2011). The results may be different if the questionnaire was not advertised via a traveler's association. To illustrate, it has been found that female ACC users prefer larger distance settings and are less likely to adjust these settings than males (Cicchino and McCartt 2015; Nowakowski et al. 2010).

In the present study, the most common car brands were Volvo, Toyota, Volkswagen, BMW, and Peugeot, which are among the most frequently sold cars in The Netherlands (AutoWeek 2015). Previous surveys in the United States included vastly different car brands such as Lexus, Infinity, and Cadillac (Bato and Boyle 2011; Jenness et al. 2008). It remains to be investigated how well our results generalize among different countries in which the types of cars, traffic cultures, and environments differ. For example, in lower-income countries, infrastructure and law enforcement are generally of poorer quality, traffic is more mixed, and acts of interpersonal aggression are more frequent (De Winter and Dodou 2016; Özkan et al. 2006; World Health Organization 2015), which are factors that could affect the use of ACC.

At present, only a small percentage of new vehicles are equipped with ACC (Öörni 2016), which implies that the effects of ACC on traffic safety and efficiency are probably small. The low use of ACC may be attributed to financial barriers and to the fact that ACC is not mandatory or endorsed by current legislative frameworks, unlike, for example, electronic stability control (Kyriakidis et al. 2015). Future research may have to employ direct marketing strategies in order to reach the smaller subgroups, such as young and female ACC users. Researchers will also have to consider that policies are changing rapidly, with the automotive industry recently having committed themselves to making autonomous emergency braking (AEB, a technology that may be combined with ACC) standard by September 2022 on light-duty cars and trucks (NHTSA 2016).

The present survey may be periodically repeated in order to keep track of year-on-year changes in pleasure and safety of ACC use as a function of technological progress. For future research, we recommend asking technical details about the type of ACC and conjoining technologies such as forward collision warning systems and AEB in order to be able to document idiosyncratic behavior associated with specific ACC features. Now that more and more cars are equipped with integrated automation systems, it may be difficult for drivers to know which subsystem (e.g., ACC or AEB) intervenes in the driving task. Hence, we recommend that future questionnaires ask respondents about the exact car make, model, and year in order for researchers to be able to interpret the results in relation to the working mechanisms of the automation system.

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ORCID

J. C. F. de Winter http://orcid.org/0000-0002-1281-8200

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