Drivers' hand positions on the steering wheel while using Adaptive Cruise Control (ACC) and driving without the system

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Abstract

Adaptive Cruise Control (ACC) is an Advanced Driver Assistance System that maintains a predefined speed and headway to the vehicle in front. Despite the expected benefits, the effects of ACC usage on drivers' behaviour are not completely identified yet. In this context, the present study was performed to investigate drivers' perceived risk and mental workload associated with the usage of ACC, through the measurement of drivers' hand positions (high, medium, and low) on the steering wheel. In addition, the study also aimed to understand the effect of sensation seeking on the drivers' hand position. A study was conducted in a driving simulator, with 26 participants who drove twice, once with ACC and once manually, along the same route. Using Wilcoxon exact test, the results showed that the percentage of high and low hand position on the steering wheel did not change while driving with ACC or manually. Besides, no differences were found between the ACC driving condition and the manual driving condition on self-reported experienced mental workload and perceived risk. However, the score on the sensation seeking questionnaire was related to the hand positions selected by the participants.

Introduction

Adaptive Cruise Control (ACC) is an Advanced Driver Assistance System (ADAS) that partly automates the longitudinal driving task by maintaining specific speed and headway to the vehicle in front, according to the settings defined by the user. The device automatically maintains the distance to a vehicle ahead by reducing fuel flow and/or actively braking the vehicle. Through the partial automation of the driving task, ACC is expected to bring a reduction of drivers' mental workload, as already demonstrated in previous studies (Stanton et al, 1997; Hoedemaeker & Brookhuis, 1998). The usage of the system might also affect the users' perceived risk during

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driving, considering that part of the task has been automated by the system (Rajaonah et al, 2008). Both variables (mental workload and perceived risk) are relevant for road safety research because they are frequently considered in studies related to road accidents (Oppenheim et al, 2010) and they also affect reliance on automation, as underlined by Riley (1996).

Mental workload can be defined as the capacity allocated to the performance of a task (De Waard, 1996) and, in the context of driving, it can be affected by several variables, including traffic density and the usage of automation such as ADAS/IVIS. On the other hand, risk perception refers to the subjective experience of risk in potential traffic hazards (Deery, 1999) and is determined by two inputs: information regarding potential hazards in the traffic environment, and information on the ability of the driver (and the capabilities of the vehicle) to prevent those potential hazards from being transformed into actual accidents (Brown & Groeger, 1988). Interestingly, previous research found that drivers' mental workload strongly correlates with drivers' perceived risk, in experimental conditions. In particular, in Fuller et al. (2008), it was found that drivers' ratings of risk were highly correlated with drivers' ratings of task difficulty (which is linked to mental workload). Similarly, Lewis-Evans and Rothengatter (2009) reported in their study that drivers' experience of task difficulty while driving in a simulator and feeling of risk during the driving task were correlated. In recent years, the assessment of hand positions on the steering wheel has been gaining validity for the measurement of drivers' perceived risk and mental workload. Compared to other measurements (travelling speed, headway to the vehicle in front and lane position), the position of the hands on the steering wheel can be easily assessed both in driving simulator and naturalistic driving studies, and, therefore, it deserves the consideration of road safety researchers.

In a first study conducted on the topic, Walton and Thomas (2005) assessed drivers' hand positions on the steering wheel of vehicles passing at different road sites. The hand positions were classified according to the number of hands on the top half of the steering wheel (that is above the dotted line in Fig. 1): two hands, one hand and no hands were the 3 categories identified. The results showed that 50% of drivers were observed with only one hand on the top half of the steering wheel. In addition, it was found that higher objective risk (related to traveling speed) led to more control hand positions.

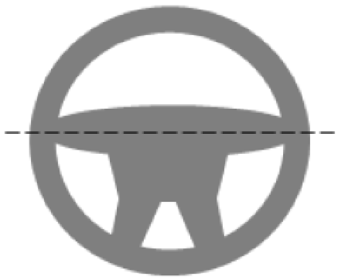

Figure 1. Hand positions measurement according to Walton and Thomas (2005)

In a subsequent study, Thomas and Walton (2007) adopted the same measurement to determine differences in hand positions on the steering wheel between SUV and car drivers. Overall, SUV drivers were observed to exert less control on the steering wheel. Given that SUV are deemed safer than other vehicles by SUV owners and by the general public (Davis & Truett, 2000), less control on the steering wheel shown by SUV drivers was related to the reduced perception of risk compared to car drivers.

Later, De Waard et al. (2010) studied the relationship between mental workload and perceived risk and hand positions on the steering wheel in a driving simulator study. Contrary to what had been done previously, the researchers adopted a different measurement to take into account also the bottom part of the steering wheel. The scoring of hand position was divided into high, medium and low control. High control meant that the left and right hands were located respectively in the left and in the right blue areas in Figure 2. Medium control meant that two hands were placed on the steering wheel, but only one (left or right) was located in the respective left or right blue areas. Finally, low control meant that the two hands were placed in the pink area in or that one hand or no hands were on the steering wheel. During the experiment, drivers had to perform a lane merging task in different traffic situations, merging lane length and number of cars in the acceleration lane. The results showed that, during the lane merging manoeuvre, a change in hand positions on the steering wheel seemed to reflect changes in drivers' mental workload and reported risk. Notably, drivers assumed a lower control position after merging into the highway, once they reached the left lane (higher speed lane). Besides, age differences were found within the panel concerning hand positions: older divers drove more often with a high control position, compared to younger drivers.

Figure 2. Hand position measurement according to De Waard et al. (2010)

In a following study, Fourie et al. (2011) collected observations of drivers' hand positions from the roadside and attempted to link them to travelling speed and headway to the vehicle in front. Concerning speeds, drivers who placed two hands on the top half of the steering wheel drove slower than drivers who placed one hand on the top half of the steering wheel. Similarly, drivers who placed two hands on the top half of the steering wheel had lower reciprocal headways than drivers who placed one hand on the top half of the steering wheel. Based on these findings, hand positions on the steering wheel were linked to drivers' characteristics (e.g., sensation seeking). In addition, the authors found gender differences in relation to hand positions.

On the whole, from the studies performed on the topic, risk perception and mental workload level seem to influence hand positions on the steering wheel. In this context, considering that Adaptive Cruise Control is supposed to influence driver's workload and perceived risk, then, the hand positions on the steering wheel should also be affected by the employment of ACC. In order to know more on the topic, in the present study, the attention was turned to how the use of Adaptive Cruise Control (ACC) might affect drivers' hand positions on the steering wheel. Based on ACC functioning, the following hypotheses were proposed:

1) The use of ACC will lead participants to adopt more frequently lower control hand positions, compared to driving without ACC.
2) The use of ACC will lead participants to adopt medium control hand positions as much as during driving without ACC
3) Driving without ACC will lead participants to adopt more frequently higher control hand positions, compared to driving with ACC.

The rationale behind these hypotheses is that the hands' positions on the steering wheel are related to the drivers' risk perception and to drivers' mental workload: during the use of ACC, drivers have lower perception of risk due to the partial automation of the driving task and, therefore, they might adopt a lower control hand position on the steering wheel. Furthermore, when using ACC, drivers have lower perceived workload and, therefore, as with perception of risk, they might adopt the position of lower control on the steering wheel. Based on this assumption, the following hypothesis was also proposed:

4) The use of ACC will be related to lower self-reported risk and self-reported mental effort, compared to driving without ACC.

Therefore, the first aim of this study is to investigate the effect of the use of ACC on drivers' workload and perceived risk, through the observation of drivers' hand positions on the steering wheel and through self-reported measures. A second aim is to investigate the relationship between drivers' hand positions on the steering wheel and the personal characteristic of 'Sensation Seeking', defined as the inclination to "seek varied, novel, complex and intense sensations and experiences and the willingness to take physical, social, legal and financial risk for the sake of such experience" (Zuckerman, 1994, p. 27). As previously reported, in a research work (Fourie et al., 2011), it was supposed that drivers' hand positions on the steering wheel are affected by personal characteristics and, in the specific case, by sensation seeking (which causes drivers to adopt higher speeds and lower headways). In order to confirm this assumption, the following hypotheses were also made:

5) Sensation seeking will be positively related to low hand positioning.
6) Sensation seeking will not be related to medium hand positioning.
7) Sensation seeking will be negatively related to high hand positioning.

Method and materials

Overall, 26 participants took part in the experiment, 24 males and 2 females with an average age of 25.3 years (*SD* = 9.0). They were selected among a group of ACC users and among staff of the Faculty of Engineering of the University of Porto.

The study was performed at the driving simulator of the Faculty of Engineering of the University of Porto. The simulator was composed of a Volvo 440 Turbo provided with the steering wheel, the pedals (accelerator, brake and clutch), the gear stick and the instrument panel. The simulated Adaptive Cruise Control allowed for the selection of the desired speed and headway to the vehicle in front through the controls on the steering wheel.

The participants drove twice in the simulated environment, once with ACC and once manually (without the system). The designed test route was a 46-km stretch of a real motorway in Portugal, divided into six sections, each one presenting different characteristics with regard to traffic conditions, length, speed limits and weather conditions. The simulated environment included other vehicles moving at 90 km/h on the right lane and at 120 km/h on the left lane. The routes were counterbalanced between the participants in order to avoid carry-over effects.

The participants were filmed during the routes by 4 cameras, recording respectively the simulated road, the driver, the steering wheel and the feet on the pedals. The hands' positions on the steering wheel were coded one of the author, according to the classification proposed by De Waard et al. (2010) and, therefore, divided into low, medium and high control. The time during which a participant kept his or her hands in one of the three positions (low, medium, high) was reported in seconds and, later, turned into percentages. Hence, each participant was characterized by three percentages (Low, Medium, High) for both driving conditions (ACC and manually). The coding of hand positions was performed only in Section 2 and Section 4 of the route because, in those stretches, the traffic was constant and no critical situations were planned.

In order to assess drivers' attitude towards sensation seeking, the Portuguese version of the Arnett Inventory of Sensation Seeking (AISS) questionnaire (Arnett, 1994) was administered. Before the first route, the pariticipants had to indicate, for each one of the 40 items, which defintion applied best for them on a four-point scale from '1 = describes me very well' to '4 = does not describe me at all'. The final score was made up of the sum of the two subscales (Novelty and Intensity), and the higher the score, the higher the driver's sensation seeking attitude. The internal consistency of the Arnett Sensation Seeking questionnaire was satisfactory, with a Cronbach's alpha value of .75.

In addition, after each route (with ACC and manually), the drivers were asked to fill in two questionnaires, one measuring perceived risk and the other one measuring mental workload. For the former, the participants had to choose what was the risk experienced during the route, on a scale ranging from '1 = no risk at all' to '10 = very high risk'. Likewise, for the mental workload, the drivers had to report the workload perceived during the task, on a scale ranging from '1 = no effort' to '10 = very high effort'.

For the purposes of this paper, the independent variables were the driving condition (drive along the same route with ACC and manually) and the score on the sensation seeking questionnaire. The dependent variables were the drivers' hand positions on the steering wheel and the ratings on the two questionnaires measuring perceived risk and mental workload. Notably, the drivers' hand position on the steering wheel was evaluated by the variation of the 2 independent variables, whereas the ratings on the two questionnaires were assessed exclusively by the variation of the driving condition.

Results

The Wilcoxon signed rank test was used to determine whether the percentages of respectively high, medium, and low drivers' hand position varied between the ACC and manual conditions. These statistical analyses were conducted with the SAS statistical package v.9.1. The results showed that the percentages of high hand positions did not significantly vary between the ACC driving condition (*Mdn* = 43.15) and the manual driving condition (*Mdn* = 46.75), $S = -47.0$, $p = .212$. The same happened with percentages of low hand positions in the non-ACC usage condition (*Mdn* = 18.15) compared to the manual condition (*Mdn* = 17.15), $S = 35.5$, $p = .378$. On the other hand, the percentages of medium hand positions were significantly lower in the manual condition (*Mdn* = 14.50) than in the ACC usage condition (*Mdn* = 30.20), $S = 72.5$, $p = .049$ (despite being this result at the limit of significance).

Concerning the two questionnaires applied after each route, no differences were found between the ACC driving condition and the manual condition on self-reported perceived risk ($S = -11.5$, $p = .570$) and mental workload ($S = -12.5$, $p = .562$).

To address the second aim of the present study, partial least squares (PLS) analysis was conducted with the SmartPLS Version 2.0 (M3) software (Ringle et al., 2005), because it does not require strong assumptions about the distributions of the data (Cassel et al., 1999; Chin, 1998) and it achieves high levels of statistical power even if the sample size is small (Chin & Newsted, 1999). To determine the inner weights, the centroid scheme was used and a uniform value of 1 was chosen as an initial value for each of the outer weights (Henseler, et al., 2009; Henseler, 2010). To evaluate the significance of the parameter estimates, a bootstrapping procedure was used, and implemented in SmartPLS. Specifically, 5,000 bootstrap samples with replacement were requested and the individual sign changes option was used (Henseler et al., 2009).

Figure 1 shows the relationships between sensation seeking and hand positioning. High and medium hand positioning were not significantly related to sensation seeking. However, consistent with our hypothesis, sensation Seeking was positively related to low hand positioning. Since SmartPLS does not compute significance tests for the variance explained in the dependent latent variables, the effect sizes of the R^2 values was calculated using Cohen's f^2. According to Cohen (1988), effect sizes of

.02, .15, and .35 are considered small, medium, and large, respectively. The effect size was moderate for low hand positioning (f^2 = .11), small for medium hand positioning (f^2 = .07), and very small for high hand positioning (f^2 = .01).

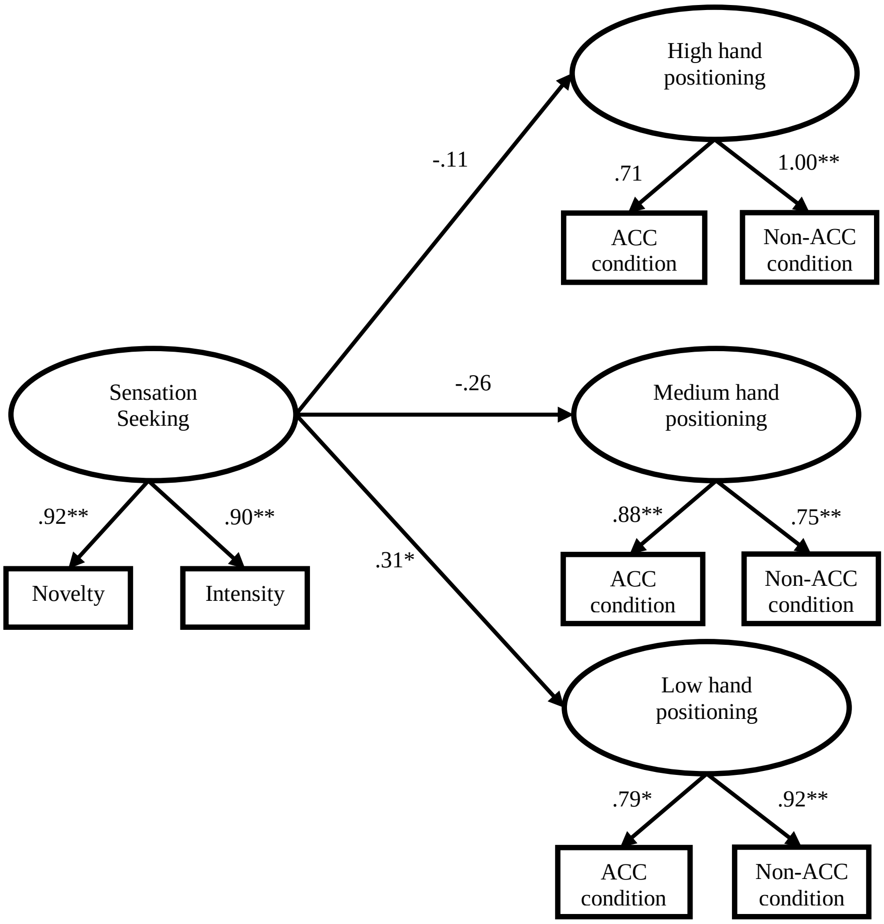

*Figure 3. Relationships between Sensation Seeking and Hand Positioning (Note. * p < .01; ** p < .001)*

Discussion

The present research was mainly conducted to detemine whether the use of ACC affects the perceived risk and the mental workload of drivers. In order to achieve this, two measurements were used: the observation of drivers' hand position on the steering wheel, and two questionnaires expressly designed for the study. The research also aimed to investigate the influence of sensation seeking on mental workload and on perceived risk, again looking at changes in drivers' hand positions on the steering wheel.

Regarding the first aim, the core assumption was that drivers tend to adopt lower control hand positions while driving with ACC, compared to driving manually. This assumption is not confirmed by the results, since low and high drivers' hand positions did not significantly vary between the ACC and the manual driving condition. Therefore, it can be assumed that use of the device does not lead drivers to perceive lower mental workload and lower risk while driving. This result is confirmed by the fact that no differences were found between the ACC driving condition and the manual driving condition on self-reported experienced mental workload and perceived risk. Those conclusions are partly in contrast with previous research (Stanton et al, 1997; Hoedemaeker & Brookhuis, 1998; Young & Stanton, 2004) that reported lower driver mental workload levels while driving with ACC. However, in contrast to this research, previous studies have provided drivers with highly demanding tasks and/or risky situations where mental workload and perceived risk are at a high level. In such conditions, the ACC could be useful in reducing these levels, through the assistance provided by the partial automation of the driving task. On the other hand, when the task is monotonous (as it was in the case of the present study), it is possible that the system cannot bring any reduction to the level of mental workload and perceived risk. In this discussion, it is interesting to note however that the percentage of medium hand positions is significantly lower in the manual driving condition than in the ACC usage condition. This result was not expected and it should receive closer attention in further research.

Concerning the second aim of this research, the results partly confirmed the hypotheses formulated. Indeed, sensation seeking was positively related to low hand positioning, to indicate that drivers with a high score on the sensation seeking questionnaire adopted lower hand positions on the steering wheel. This outcome might be seen as confirmation of the fact that sensation seeking is strongly correlated to risky driving (Jonah, 1997) and also show coherence with the results reported in Fourie et al. (2011).

Overall, two main results can be drawn from this study:

1) The use of ACC does not influence the driver's mental workload and perceived risk;
2) Sensation seeking significantly affects hand positioning, as an indicator of perceived risk.

Some limitations should be mentioned about the work performed. First of all, the small sample size (26 drivers) might have prevented the finding of relationships between the variables (usage of ACC and drivers' hand positions), and could have led to a reduced capacity for detecting their effects. Besides, the methodology used could be regarded as a second limitation, due to the uncertain level of fidelity encapsulated within the simulated environment, which can be both physical and functional (Stanton, 1996). Finally, another limitation is related to the coding of drivers' hand positions that has been done by a single researcher, and that might have caused an interpretation bias. However, it should be noted that this research was mainly designed as an exploratory study, and, therefore, the limitations mentioned above are acceptable. Besides, since this work addresses a quite new and unexplored research field, it can contribute to influencing the future research directions mentioned below.

First of all, the effects on driver behaviour caused by the use of Adaptive Cruise Control appear to be still rather unclear, and further clarification is required as to whether the device produces an increase or a decrease in drivers' mental workload and perceived risk. With respect to this, further investigations are also needed into whether these two constructs can actually be considered to be linked to each other, and therefore evaluated together. Besides, future studies should also confirm whether drivers' hand positions can be considered to be a reliable indicator of mental workload and perceived risk. Finally, in previous research it has been found that drivers' hand position is affected by several variables (e.g. age and gender). Due to the small number of studies on the topic, it would be interesting to once again test and validate those relationships in other contexts and situations, and to evaluate other factors (e.g. level of traffic, type of road and weather conditions), that could affect drivers' mental workload and perceived risk.

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