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RESEARCH ARTICLE

The Impact of Adaptive Cruise Control on the Drivers' Workload and Attention

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ABSTRACT Workload and distraction are problems that affect road driving and can cause very serious accidents. Drive assistance systems are very important to help drivers relieve fatigue of driving by increasing road safety and reducing the number of accidents. The Adaptive Cruise Control (ACC) is a useful driver assistance system to set and maintain a safe distance from the front vehicle, modulating speed and limiting sudden braking. However, the effects of the ACC on overall driver behaviour have not yet been thoroughly investigated. In this study, the authors assessed the influence of ACC on mental workload and attention of drivers in a real driving environment. The results of several evaluations were considered: subjective assessment of workload (NASA-TLX), physiological measurements of workload (brain activity through electroencephalographic technique and the analysis of visual behaviour through an eye monitoring device) and performance-based measurements (via Vbox Pro Video mounted on the vehicle). 52 drivers were involved in the study, 26 ACC experts and 26 non-experts, who drove along the ring road of Bologna (Tangenziale di Bologna) (Italy), both using ACC and manually, without the help of any device. During the test a secondary task was introduced: the sudden arrival of a braking car. Results showed that the use of ACC increased distraction when driving.

INDEX TERMS Adaptive cruise control, mental workload, driving attention, electroencephalography, eye tracking, human factors.

I. INTRODUCTION

Increasing traffic is a major problem in all cities. More and more vehicles are moving on the roads, causing an increase in the number of accidents, sometimes very serious and even fatal. This is often due to high speeds, workload and distraction of drivers. Countless stimuli, both visual and audible, can distract drivers. Those come from outside (signals and road signs of different colors, traffic lights, noises, etc.) as well as from inside the cars, today increasingly equipped with bright devices and speakers. While technology helps drivers with automatic driving control systems, on the other hand, the responsibility of the driver cannot be disregarded, as he still plays a key role in vehicle management.

Among the most useful and used technological devices is certainly the Adaptive Cruise Control (ACC), one of the Advanced Driver Assistance System (ADAS) Level 2. Level 2 systems are considered ''hands-off'' devices and can control multiple car functions. Nevertheless, the driver is forced to make many decisions and therefore his role is not completely replaced by the instrument, but there is active cooperation between the driver and the automatic device [1].

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Users of level 2 devices are partially relieved of the fatigue of driving, as they have hands and feet free even if their mind is constantly engaged in driving control [2], [3]. In fact, these devices do not work independently. The driver must decide whether to activate the system at his disposal or act directly, accelerating or braking, using the appropriate buttons or pedals [4], [5].

With ultrasonic sensors and cameras, Adaptive Cruise Control (ACC) detects the complexity of the surrounding environment, the actual traffic conditions, and sets vehicle speed and performance accordingly [6]. By automatically setting the safety distance from the front vehicle and adjusting the cruising speed, this device can limit sudden braking [7], [8], [9]. Today the ACC is mainly activated for long trips, or on motorways where the speed limit is higher (99%), but it is also used on urban and suburban roads (95%), depending on traffic conditions [10], [11]. Different research fields use ACC systems. An example is the analysis of vehicular traffic congestion in both urban and extra-urban areas [12], [13]. Despite the undoubted usefulness of the ACC in reducing and mitigating the severity of road accidents, problems remain related to its use. For example, the device cannot detect a vehicle behind a curve, or small vehicles such as motorcycles or scooters, or it cannot yet identify a stationary vehicle, especially in case of poor visibility due to rain or fog [14], [15], [16], [17], [18], [19], [20], [21]. Even in these cases, the driver has an active key role in responding appropriately.

For all these reasons, it is very important to study the interaction between ACC systems and driver behaviour, to better understand how this cooperation can affect the driver's attention and workload. Driving consists in a continuous control activity in constantly changing environments. This requires persistent attention as well as a considerable mental workload, both of which are basic driving performance and road safety factors [22]. Subjected to an extreme mental workload, drivers may react late to external stimuli or even not respond at all because the amount of information exceeds their ability to realize and understand them. On the other hand, when the mental workload is below an acceptable threshold, drivers get bored, feel under-engaged and are more likely to make mistakes when driving [23], [24], [25], [26], [27], [28]. Therefore, a proper balance between mental workload and driver effort could contribute to improving both road safety and the correct use of the ACC system [29].

Basically, methods for measuring the mental workload of road users can be divided into three main groups: subjective assessments; performance measure using a dual-task paradigm; physiological measurement, namely the physical response to increased mental activity.

Subjective assessments are one of the most widely used techniques for measuring mental workload because they are reliable, low-cost and easy to implement. However, these remain subjective methods, related to memory capacity or self-analysis of participants. Sometimes, the latter may also misunderstand the perception of their own performance and the mental workload produced or confuse mental and physical load. The most widely used detection system is the NASA-TLX (Task Load Index), which evaluates mental and physical workload, perceived performance, time demand, effort and frustration [30], [31].

The measurement of overall performance is based on the relationship between mental workload and actual performance. The purpose is to check whether the driver can perform two activities simultaneously, one primary (driving) and one secondary (eg mirror control, response to audio or visual stimuli, braking) in a realistic test environment. It must be said that an increase in mental workload does not necessarily imply a decrease in driver performance. The user may be able to maintain the same level of performance by increasing effort or changing strategy [32], [33]. In addition, the secondary activity may confuse the performance of the primary action, as the driver may not carry out the main activity before performing the secondary activity. This can cause problems in measuring changes in the execution of the secondary task [34], [35], [36].

Finally, physiological measurements tend to go beyond the limits of subjective measurements, in which they capture "unconscious" phenomena that are behind drivers' behaviours, thus obtaining an objective measure of their mental states [37], [38], [39], [40], [41], [42], [43]. However, most of these research studies were conducted in simulators or unrealistic environments [44], which strongly affects the real mental load to be measured [45] and without considering any multimodal approach.

In the mid-1990s [46], for example, a simulator study to assess the influence of ACC on rapid braking to prevent a collision with a vehicle suddenly appeared in front, showed that ACC does not facilitate driving. In fact, drivers performed the task relatively well, but their reaction time increased. However, only performance-based measurements (braking behaviour) and subjective assessments (NASA-TLX) were taken into account. Anyway, the same results were obtained by another research in 2012 and another one in 2015 [47], [48]. In these cases, the mental workload of drivers was evaluated only through physiological measurements (parameters of the car via Vbox Pro Video device mounted on the vehicle).

In 2011, another study [49], conducted with a simulator to assess the influence of ACC on driving behaviour, evaluated drivers on both road and motorway with and without ACC. Using only performance-based measurements (maximum speed and driver reaction time), the conclusion was that, with ACC ON, driver reactions were delayed in critical situations, such as a sharp turn or a fog bank. The performance of eight drivers, driving five weeks under realistic conditions, was monitored and evaluated in 2017 [50] considering spacing, direction, speed, acceleration, lane use, and number of lane changes. The lowest reaction times were detected under ACC ON conditions. Studies conducted with simulator in 2002, 2012 and 2019 gave the same results. Even years earlier, in 1998 [51], [52], [53], [54], [55], 38 drivers were involved in a simulator study. They had to drive on a motorway, with ACC or manually. Higher speeds were detected with ACC ON because drivers fully trusted the system performance.

In addition, several simulation studies in 1997, 2000, 2005, 2002 and 2007 [56], [57], [58] used performance-based measures to test the influence of ACC on driver distraction. The results showed the use of ACC reduced driver awareness of the situation as well as his attention. Through psychological parameters (place of control, safety, workload, stress, etc.), another research [59] motivated this decrease in driver attention by being relieved of active driving due to the presence of the device. As a result, he focused his attention elsewhere than driving.

A work [60] also investigated the behavioural adaptation, namely the physical reaction time to braking, of eighteen drivers, with or without ACC, following another vehicle. Performance-based measures showed that with ACC ON the behavioral adaptation was higher, since drivers were more focused on secondary braking activity. As a result, the response time to a dangerous condition increased. The same conclusions were also confirmed by a driving simulator study [61], [62], [63]. Finally, subjective assessments [64] examined the effects of ACC on drivers' workload and their actual awareness of dangerous situations. Both parameters were worse with the use of ACC than with manual driving.

In this study, the authors evaluated the influence of ACC on mental workload and attention of drivers in a real driving environment. Different types of measurements were considered, adopting a multimodal approach, integrating the results of different techniques: subjective workload assessment (NASA-TLX), physiological workload measurements (brain activity through Electroencephalographic Technique and visual behaviour through the Eye Tracking device) and performance-based measurements (car parameters through Vbox Pro Video device mounted on the vehicle).

Thanks to a multimodal approach, this study aims to:

- better understand the effects of ACC on driving to assess how and how much ACC can affect the mental workload and attention of drivers. Both experienced and inexperienced ACC users were evaluated to assess the influence of previous ACC knowledge
- compare the different measurement systems used to demonstrate the complementarity of the results obtained.

This paper continues as follows: Section II describes the experimental protocol and the analysis carried out; Section III illustrates the results obtained; Section IV conclusions.

II. MATERIALS AND METHODS

A. THE EXPERIMENTAL PROTOCOL

Fifty-two drivers were involved in the study: 26 with no previous experience of ACC (Average age = 40.84 years; Range: 35 ÷ 55; SD = 5.57) and 26 ACC users (Average age = 45.81 years; Range: 35 ÷ 50; SD = 6.02). They used the systems for at least 3 months (average number of hours of experience with ACC = 3.31 years ± 1.81, range: 1 ÷ 5). The average driving experience was 22 years (SD = 6.89) for non-ACC users and 27.81 years (SD = 6.02) for ACC users. Participants were selected to have an experimental group homogeneous in age, sex and driving experience. Everyone enjoyed perfect vision, and no one wearing glasses or lenses, to avoid distorted visions while monitoring eye movement. All had valid driving licenses and none of them had previous experience of driving on the road segment considered in this study. Moreover, all participants were not aware of the purposes of the study to avoid prejudices about their behavior. Finally, all were regularly paid. The experiment was carried out following the principles outlined in the Declaration of Helsinki of 1975, as revised in 2000. The study was approved by the Ethic Committee of the University of Bologna. After a thorough explanation of the study, informed consent and permission to use the graphic video material was obtained from each participant in the experiment by signing on paper. A Volkswagen Touran equipped with automatic transmission and diesel engine and Adaptive Cruise Control (ACC) was used for the test. The ACC system of the vehicle allows for the programming of different distances based on the speed of the lead vehicle. There are 5 different levels: very small, small, medium, large and very large distance. Each level corresponds to 10 meters. During the experiment, to evaluate and compare the perception of ACC USER and ACC NO USER while driving in different conditions, the distance was set to the highest level before the test started in order to have the safest condition. Drivers had to cover the "Tangenziale" of Bologna (Italy), a coplanar ring road with the urban section of the A14 motorway (Figure 1).

FIGURE 1. The experimental site along the Tangenziale of Bologna (Italy).

That is a busy two-lane road (plus an emergency lane). Mainly straight, it has wide radius curves, with intersections only at the junctions with other roads. The speed limit is 90 km/h. This road was chosen because it has the right requirements to evaluate the Adaptive Cruise Control. Speeds above 60 km/h are allowed, there are more lanes in both directions and road signs are in good condition. The above features allowed all participants to drive safely, as they would normally do in the car, behaving naturally.

The route consisted of two rounds of a "circuit" about 5 km long. After a proper test briefing, each driver had to repeat the circuit twice on the same day. The first lap was considered an "adaptation lap", as it was useful for the rider's adaptation to the route, vehicle and ACC system. During this ride, the driver was free to experiment with the ACC system. During this lap, the user drove half of the track with ACC (ON condition) and the other half manually (OFF condition). The order of the ACC ON and OFF conditions was random to avoid any effect resulting from knowledge of succession. During the test lap (the second) a secondary task was introduced. Three times and for both ACC ON and OFF conditions, "events" were simulated, involving a car entering the traffic flow in front of the test vehicle. This is one of the most recurring critical events that forces the driver to brake quickly to avoid an accident (Figure 2). Only the data recorded during the second round with the "events" were taken into account for analysis.

According to Rudin-Brown et al. [61], the type of event was chosen because it was more likely to be consistent with the operational mode of the ACC, as well as the safest to implement, without particular risks for the participants in the experiment and for traffic in general. Before and after the test, drivers were asked to fill in the following questionnaires:

- a questionnaire on their driving style (DS), developed by the Department of Psychology of the University of Bologna, to identify driving style and habits
- a personal questionnaire (PQ), showing the present age, level of education, and age of driving
- a questionnaire on ACC (Q-ACC), showing how reliable the ACC system was for participants
- NASA-TLX (NASA), designed to assess user workload during driving test.

Throughout the experimental protocol, both drivers and vehicles were equipped with different devices. Physiological data were recorded through dedicated techniques. For example, brain activity was recorded by electroencephalography (EEG) and visual behaviour through eye tracking (ET). In addition, driving behavior data was collected thanks to a professional device mounted directly on the car (i.e. a Vbox Video Pro).

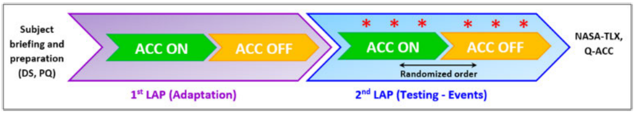

FIGURE 2. **Overview of the experimental protocol (the red asterisks represent the events).**

B. DATA COLLECTION

ET and EEG devices were calibrated at the start of the tests for each driver. Participants were asked to sit on the stationary vehicle to set up the instruments.

First, the user put on the ET device, which consisted of the following units (Figure 3):

- the Spectral Mounted Unit (SMU) - two cameras, mounted above a specific glass. The eye camera is focused on the driver's right eye and records all pupil movements thanks to a mirror reflecting the infrared spectrum. The scene camera is intended for recording the external environment
- the Display Transmit Unit (DTU) – a small display with a transmission unit, which continuously monitors the eye movements and the external scene
- the ME computer - equipped with ASL Mobile Eye-XG software, able to process the video corresponding to eye fixations on the scene.

The sampling frequency of the eye movement was 30 Hz (time resolution of 33 ms), and the spatial accuracy was 0,5-1 p.m. [65]. During the calibration phase, subjects had to fix specific points of the environment to achieve the accuracy of the user's views along the entire route.

Second, the user puts on the EEG system (Figure 3). The EEG head cap is made of elastic textile material and is the necessary support to keep the measuring electrodes in specific positions, according to a standard defined as International System 10-20. For the test, the headcap was configured with 16 EEG channels positioned on frontal and parietal areas, corresponding to the brain cortical areas most involved in mental workload [66]. In particular, the following EEG channels were collected: FPz, AF3, AFz, AF4, F3, Fz, F4, P7, P3, Pz, P4, P8, PO3, POz and PO4, while Cz acted as system ground.

The electrodes used were passive Ag/AgCl (Silver and Silver Chloride), connected to an amplifier in a unipolar configuration, i.e. the electrical activity recorded by each electrode relates to the same reference potential. This refers to the average potential recorded by two electrodes placed on the earlobes. A biomedical conductive gel was applied to each electrode to adapt the skin-electrode impedance and ensure high signal quality. All impedances were kept below 20 kΩ. EEG data were collected through the BEmicro digital monitoring system (EBNeuro, Italy), with a sampling frequency of 256 Hz. The heart activity was also monitored, thanks to an electrode placed on the chest, to provide a complete picture of the individual's condition, but it was not considered in the present study. The main advantage of the EEG lies in the compactness of its amplifier. The latter allows real-time recording in Holter mode, minimizing invasiveness and encumbrance of the system during the experiment and temporarily saving the data on the internal memory.

Two 1-minute reference conditions were recorded before driving. First of all the participant, outside the car, was invited to remain relaxed with his eyes closed (CE condition). Then, sitting in the driver's seat inside the car, the same participant was asked to remain relaxed looking forward (OE condition). The purpose of this calibration was to estimate the individual neurophysiological parameters of the driver, which were necessary during data analysis (refer to the next paragraph) [67]. The vehicle was equipped with a Video Vbox Pro data recorder (Figure 3). This device combines a powerful GPS with a high-quality multi-camera, consisting of two paired cameras that work in sync. Video V-Box Pro was placed in the centre of the vehicle, while the two cameras were installed on the dashboard. The GPS sensor was positioned on the roof of the car, in a barycentric position, for greater accuracy of measurements. The different parameters supplied in output from the GPS and emitted with a frequency of 10 Hz refer respectively to the position along the circuit, lap times, speed (accuracy of ± 0.1 km/h), acceleration (1% accuracy), and distance at a sampling rate of 20 Hz [68].

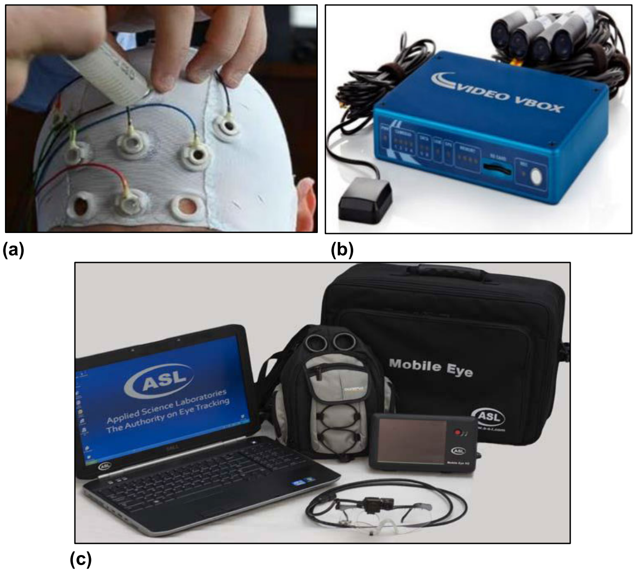

FIGURE 3. The EEG system (a), the Video V-Box Pro (b), the Eye Tracking Mobile EYE-XG (ME) (c).

As already mentioned, before the test drivers were asked to complete a questionnaire on their driving style (DS). Developed by the Department of Psychology of the University of Bologna, it was a self-assessment questionnaire on the user's driving style and habits consisting of twenty-seven questions. On a scale of 1 (never) to 6 (always), the user had to assess his driving behaviour by considering compliance with speed limits and safe distance, driving with or without a mobile phone, respect for vulnerable users (pedestrians and cyclists), etc. In this way, it was possible for each driver to evaluate the risk appetite and tolerance and the risk threshold while driving.

After the test, each driver completed a questionnaire on ACC (Q-ACC) and NASA-TLX (NASA). In the first they had to answer twenty-one questions, on a scale from 0 to 6, and subjectively evaluate the following:

- level of attention and distraction while the driving
- the driving experience during the test. The user had to evaluate the complexity of the test, his ability to control the situation, to understand when to take control of the vehicle, etc.
- perceived reliability and usefulness of the ACC system in improving safety.

NASA-TLX, on the other hand, was used to evaluate, on a scale from 0 to 100, the mental, physical and temporal needs of the driver during the test. The performance achieved, the effort produced, and the frustration suffered were also measured. The final result provided a score representing the overall workload experienced. In this way, it was possible to obtain the perception of the mental workload of drivers together with their subjective evaluation of the level of attention or inattention and compare them with the EEG results.

C. DATA ANALYSIS

1) VISUAL BEHAVIOR

The visual behavior of drivers was obtained by the elaboration of users' points of attention recorded during the test. A video for each driver was created using the EYE-XG software that shows a cross on the scene at the eye fixations. This allows detecting the sequence of fixations for all drivers.

Each frame of the video was examined and quantified manually and assigned to an element of the scene according to different categories: dashboard, cars (vehicles on the road), background (sky and vegetation), road (pavement and safety barriers), side mirrors, internal mirror, interior car (except for the dashboard), vertical signs (Figure 4).

FIGURE 4. EYE-XG frames assigned to car, background and dashboard categories.

The frames were collected into two macro-categories: attention and inattention. The first contained all the frames in which the driver-focused attention on the driving scene; the second, instead, consisted of frames in which the user was distracted from the driving scene and looked sideways (Figure 5).

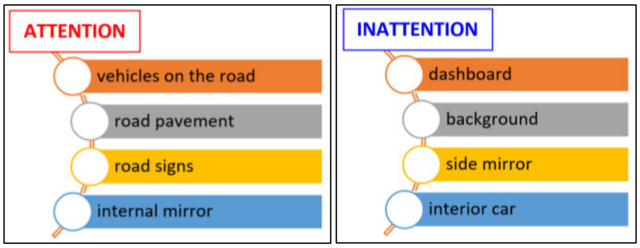

FIGURE 5. EYE-XG frames assigned to attention and inattention macro-categories.

For both ACC ON and OFF conditions, the number and duration of fixations of each element were computed by multiplying by 33 ms the number of frames in which a single target object was fixed [69]. The minimum duration of a fixation was two frames (66 ms) to avoid the inclusion of saccadic movements. This limit is lower than that commonly used in others eye -tracking experiments, that is 100 ms. In this case, being a real-world driving setting where the environmental and traffic patterns change very dynamically, quick fixations may occur [70], [71], [72], [73], [74], [75], [76].

2) EEG BEHAVIOR

During experiments, EEG data was recorded without any signal conditioning, the whole processing chain was applied offline. EEG signal was first band-pass filtered with a fourth-order Butterworth filter (high-pass filter cut-off frequency: 1 Hz, low-pass filter cut-off frequency: 30 Hz). The Fpz channel was used to remove eye-blinking from each channel of the EEG signal using the REBLINCA algorithm [77]. This step is necessary because the blinking of the eyes could affect the frequency bands related to mental workload, especially the theta EEG band. This method allows the correction of the EEG signal without losing data.

For other interferences (i.e. environmental noise, driver movements, etc.), specific procedures of the EEGLAB toolbox [78] were employed. First, the EEG signal was segmented into epochs of 2 seconds (Epoch length), through moving windows shifted of 0.125 seconds (Shift), thus with an overlap of 0.875 s between two contiguous epochs. This windowing was chosen to have both a high number of observations compared to the number of variables, and to respect the stationarity condition of the EEG signal [79]. This condition is necessary for spectral analysis of the signal. EEG epochs with a signal amplitude greater than $\pm 100\ \mu$V (Threshold criterion) were marked as "artifact".

After that, each EEG epoch was interpolated to check the slope of the trend line within the considered epoch (Trend estimation). If this slope was greater than 10 μV/s, the epoch considered was marked as "artifact". Finally, the signal sample-to-sample difference (Sample-to-sample criterion) was analysed. If this difference, in terms of absolute amplitude, was greater than 25 μV, that is, a sudden (non-physiological) variation occurred, the EEG epoch was marked as "artifact". Eventually, the EEG epochs marked as "artifact" were removed from the EEG dataset to have a clean EEG signal to perform the analyses.

Starting from the EEG dataset obtained, the Power Spectral Density (PSD) was calculated for each EEG channel and for each epoch using a Hanning window of the same length of the considered epoch (2 seconds length, which means 0.5 Hz of frequency resolution). Then, the EEG frequency bands of interest were defined for each subject by the estimation of the Individual Alpha Frequency (IAF) value [80]. In order to have a precise estimation of the alpha peak and of the IAF, participants were asked to keep their eyes closed for a minute before starting the experimental tasks (CE condition, refer to the previous paragraph). Only the theta band [IAF – 6 $\div$ IAF – 2], over the EEG frontal channels, and the alpha band [IAF – 2 $\div$ IAF + 2], over the EEG parietal channels, were considered variables for assessing the mental workload [81], [82].

Then the EEG-based neurometric workload was calculated. To quantify mental workload, the ratio between Theta rhythms on frontal sites ("ThetaF") and Alpha rhythms on parietal sites ("AlphaP") was estimated, as a well-established metric in this type of calculation [83]. In fact, it has been shown that ThetaF/AlphaP increases with increasing mental workload experienced by the user [67], [84], [85]. The measurement considered the ratio between PSD values, individually normalized with respect to the OE baseline condition (refer to the previous paragraph), averaged in theta band over the frontal electrodes (AF3, AFz, AF4, F3, Fz, F4) and the mean PSD values in alpha band over the parietal electrodes (P3, P7, Pz, P4, P8, POz).

3) DRIVING BEHAVIOR

The driving behaviour was extrapolated from the video recorded by Video V-Box Pro that allows to evaluate the kinematic parameters of the car. For both ACC ON and OFF conditions the mean speed of the vehicle and the minimum average distance between the two cars during the events were evaluated. To measure them, the EYE-XG software videos were synchronized with the Video V-Box Pro videos, in order to associate the drivers' visual gaze behaviour and the vehicle movements. The event was considered as the time between switching on and off the red light of the main vehicle).

III. RESULTS OBTAINED AND DISCUSSION

Results obtained concern only forty-eight subjects, as four participants were rejected due to technical problems with the ET and EEG data.

A. THE INFLUENCE OF ACC ON VISUAL BEHAVIOR

Figure 6 shows the influence of ACC on the visual behaviour of drivers. The analysis revealed that the average percentage of attention frames decreased using ACC. When ACC controls the vehicle, drivers feel safer and tend to turn their attention away from driving and engage in secondary tasks. On the contrary, without ACC drivers focus their attention on the road ahead. This trend is independent of previous ACC knowledge but is more evident for ACC inexperienced users (-17%, $\chi^2 = 6.05$, $p = 0.002$) than for experienced ACC users (-10%, $\chi^2 = 3.25$, $p = 0.002$).

These results were confirmed during individual events. The average percentage of attention recording frames was higher in the ACC OFF condition, even when the driver was engaged in the secondary task (following a braking vehicle and keeping the right distance to include it in the driver's field of view). 288 observations were recorded, involving 48 participants - 3 events -2 ACC condition, F(1, 288) = 88.59, $p < 0.001$, $\chi 2 = 0.37$ (Figure 7).

For the same event, the ACC-experienced users were less distracted from the driving scene than users without ACC experience. In the ACC ON condition, the experienced drivers kept almost constant attention during the succession of events. On the contrary, the inexperienced drivers showed a decreasing level of attention from the first to the third

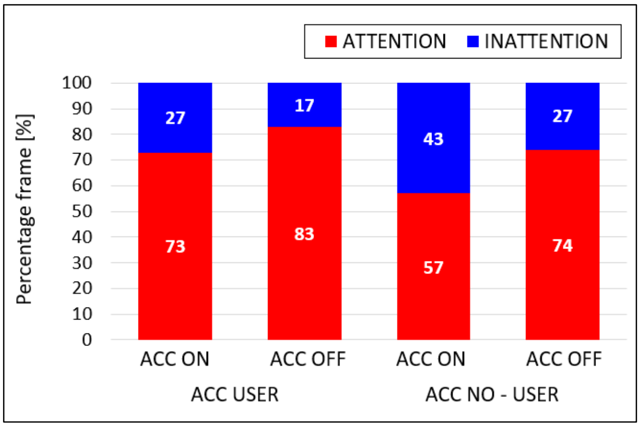

FIGURE 6. Attention and inattention frames for ACC ON and OFF conditions, between ACC experienced and no-experienced users.

event. In fact, even if they realized that the vehicle in front of them was suddenly braking, their concentration on the driving scene did not increase. This fact points out that drivers tend to use the Adaptive Cruise Control as a replacement for the task of driving and have a good degree of confidence in the system and its proper functioning.

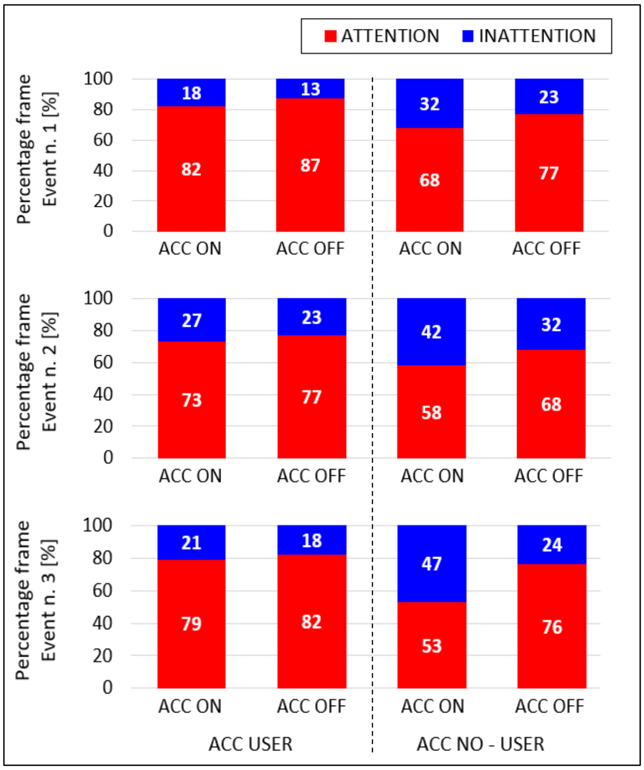

FIGURE 7. Average percentage of frames during the events, considering ACC state and drivers' ACC experience.

With ACC ON, both experienced and inexperienced drivers focused their attention more on the interior of the vehicle than on external events, to monitor whether the system was working properly. The average number of attention frames on the dashboard using ACC (36 for ACC non-users (SD = 12), 23 for ACC users (SD = 17)) was always higher than that with manual driving (4 for ACC non-users (SD = 8), 3 for expert (SD = 11)) (Figure 8). With ACC ON drivers were less focused on the driving scene and other vehicles on the road. The average number of "road and vehicles" frames with ACC ON (171 for ACC non-users, 161 for ACC users) was always lower than with ACC OFF (227 for ACC non-users, 296 for experts) (96 observations (48 participants - 2 ACC conditions), $F(1, 96) = 7.17$, $p < 0.002$, $\chi^2 = 0.12$).

For both types of users, this trend was evident also during the sudden events, where the function of maintaining the correct safety distance was performed by the ACC. Even in these cases, drivers fixed the dashboard checking the correct functioning of the system instead of watching the vehicle brake. On the contrary, with ACC OFF, drivers focused their attention on the vehicle ahead, monitored its motion and the moment of braking (161 versus 227 frames for ACC users and 171 versus 296 frames for ACC non-user) (288 observations (48 participants - 3 events -2 ACC conditions), $F(1, 288) = 3.91$, $p < 0.002$, $\chi^2 = 0.25$).

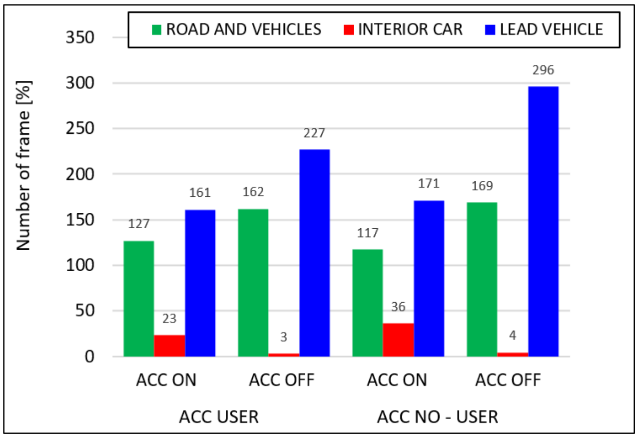

FIGURE 8. Average number of frames on the road and the vehicles, the car dashboard, and the lead vehicle during the events, considering ACC state and drivers' ACC experience.

B. THE INFLUENCE OF ACC ON MENTAL BEHAVIOR

To define mental behaviour, the overall workload was evaluated, both with objective and subjective measurements. In the first case, the EEG-based workload neurometric computed from the driver's brain activity was used. For a subjective assessment, the workload was evaluated through the NASA-TLX questionnaire.

Regardless of having previously used the ACC system or not, in the ACC ON condition the EEG drive workload was higher (96 observations (48 participants - 2 ACC conditions), $F(1, 96) = 3.29$, $p < 0.02$, $\chi 2 = 0.04$) (Figure 9). Considering the results obtained from the analysis with the Eye Tracker, the driver seemed very involved in monitoring the interior of the car, to continuously make sure that the activated ACC system worked properly. Monitoring the proper functioning of the ACC system became a sort of secondary task. This increased the overall mental workload and probably decreased the attention resources assigned to the primary task, namely driving the car.

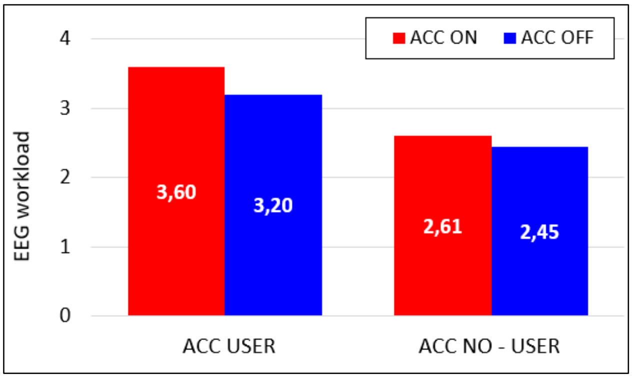

FIGURE 9. EEG workload considering ACC state and drivers' ACC experience.

The analysis of NASA TLX results showed that for all drivers the experienced workload was quite low. The driving task was not particularly difficult, hard or tiring. In addition, whatever the experience with the system was, all participants agreed that the workload with ACC OFF was higher than with ACC ON, because the use of the system made driving easier. (Figure 10).

Skilled users experienced a greater difference between using or not using the system. This result is probably due to the habit that conditioned them when driving without the ACC system they normally use. As shown in Figure 10, ACC users experience greater frustration during the constrained driving experience, compared to ACC NO-user, as they are used to using the system.

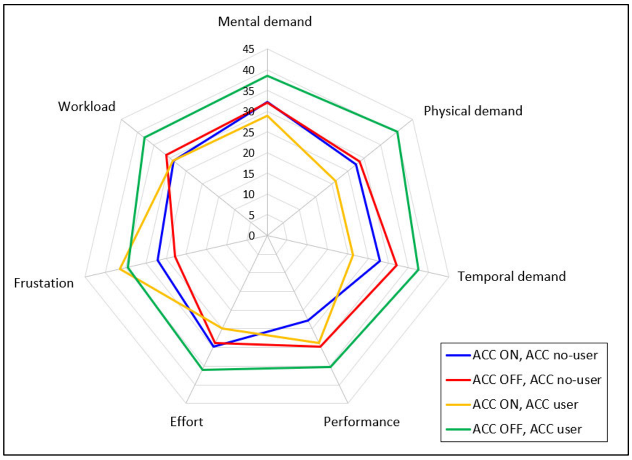

FIGURE 10. Results from the NASA-TLX questionnaire (score from 1 to 100).

These results were confirmed by the answers of DS and Q-ACC (Table 1). Participants considered the driving test neither difficult nor demanding. Regardless of their previous experience with ACC, all drivers did not realize the carelessness connected with the use of the system. They thought they had maintained a high level of attention throughout the test and believed they had been able to deal promptly with sudden and dangerous situations. They were supportive and inclined to use Adaptive Cruise Control and appreciated its usefulness to increase traffic safety. ACC's inexperienced drivers appreciated the system less than experienced users. They said they needed more time to adapt to the new system.

TABLE 1. Results of the DS and Q-ACC questionnaires.

Questionnaire	Question	ACC NO USER		ACC USER	
		Mean	SD	Mean	SD
DS (rating scale 0-5)	Exceed the speed limits	2,8	1,4	3,5	1,3
	Danger driving behaviour	1,7	0,4	1,8	0,5
Q-ACC (rating scale 0-6	Level of attention	4,6	1,3	4,7	0,9
	Test complexity	3,1	0,9	3,4	0,8
	ACC evaluation	3,4	0,6	4,1	0,5
	Utility of ACC	4,0	1,5	4,8	1,8

C. THE INFLUENCE OF ACC ON DRIVING BEHAVIOR

The VIDEO V-BOX PRO was used to evaluate general driving behaviour. For this purpose, the average test speed and the average minimum distance from the front vehicle during the planned events were taken into account. Video analysis started by synchronizing the eye-tracking videos recorded by the ASL mobile eye tracker with VBOX videos. This synchronization is useful to associate the visual behaviour and speed of drivers.

The results show that ACC did not significantly affect the vehicle speed during the test. The average lap speed was 67 km/h (SD = 12.2) and 70 km/h (SD = 11,4) for ACC users and 61 km/h (SD = 10.8) and 62 km/h (SD = 9.7) for non-users, respectively in ACC ON and OFF conditions. On the contrary, the minimum average distance from the vehicle ahead increased with ACC (18.93 m and 28.3 m for ACC users, and 16.4 m and 21.7 m for non-users, respectively for ACC OFF and ON conditions), confirming the active role of the system in ensuring safety (288 observations (48 participants - 3 events - 2 ACC conditions), $F(1, 288) = 2.21$, $p = 0.02$, $\chi^2 = 0.041$.

IV. CONCLUSION

This study evaluated the influence of Adaptive Cruise Control on drivers' mental workload and attention in a real-world driving environment. The ACC system is one of the most widely used systems for driver safety and mental workload relief. However, the presence of driver assistance systems can be distracting for users who feel more confident and pay less attention to the road. For this reason, both experienced and inexperienced ACC drivers were examined in the present study. The aim was to assess how ACC affects drivers in a real driving environment. The assessment of workload and attention of drivers was carried out by monitoring user eye movements, car parameters and driving workload by both subjective (NASA-TLX) and objective (EEG device) methods. The different measures were then compared and integrated. The results obtained were complementary, thus strengthening the validity of the method used. The results of ET and EEG devices confirmed that the Adaptive Cruise Control affected workload and inattention of both experienced and inexperienced drivers. When the ACC system was in operation (ACC ON condition), drivers tended to use it as a substitute for driving, focusing their attention on the interior of the car and, in particular, on the dashboard to monitor whether the system was working properly. This meant distraction from the driving scene. When the system was turned off (ACC OFF condition), drivers focused more on the driving scene, paying more attention to road and traffic. This trend was confirmed both throughout the test and during individual external events. For both ACC experienced and inexperienced drivers, the workload detected by the EEG increased when the device was switched on. Unexpectedly, the overall workload of drivers already accustomed to using the ACC system was higher than the workload of non-expert drivers. These results emerged from the analysis of the brain activity of drivers (EEG) and were partially confirmed by the subjective measures. Hypothetically it could be a phenomenon linked to two different types of learning. In fact, inexperienced drivers only had to familiarize with the new automated system, while experienced drivers, accustomed to the ACC mounted on their vehicle, had to get used to the new device, but also change their habits related to the use of a similar yet different system. This shows how important training is when introducing new systems, including automated ones. It's crucial to teach people how to use and interact with those devices. Considering that technology has made the tools to do the EEG less invasive, thus making the exam more comfortable [86], [87], neuroscience could provide an additional and valuable perspective on driver behaviour [88], [89], [90], [91]. In any case, the distraction from the driving scene with ACC ON did not correspond to safer driving. The average lap speed measured by the VIDEO V-BOX PRO was very similar for all users in all conditions (ACC ON, ACC OFF). The results of the subjective assessment of mental workload (NASA-TLX and DS and Q-ACC questionnaires) also showed that drivers did not notice they were distracted by ACC and were not aware of the potential danger. Drivers believed they maintained a high level of attention throughout the test and thought they were able to deal promptly with sudden and dangerous situations. In general, the task of driving was not particularly tiring for them. In addition to the expected benefits of the ACC, the results obtained could be valuable to improve the usability of the ACC and design appropriate adaptive automation strategies, thus increasing road safety. However, results obtained should be carefully considered for a number of reasons and in the light of several findings: drivers wore equipment that during the test affected their mobility; none of them had previous experience of driving on the road segment considered in this stud; they knew they were being monitored during the experiment.

Finally, the analysis of human factors suggested the possibility of distinguishing users into two macro-categories, depending on their different relationship with an automatic ACC device. The result is two different approaches to the automated system that could be defined as either confident or prudent.

The confident user is the one who tends to delegate some tasks to automation. He has the perception of being allowed to relax or devote his attention to something else, such as consulting the on-board navigator, checking the consumption of the vehicle, talking to other people or on the phone, reading messages received on the smartphone. During the test the ACC device offered frequent opportunities for "controlled distraction". In these spaces of inattention, the user, while remaining in overcontrol, was aware of devoting part of his attention to something else, relying on a technological support. The confident user is aware of both the effects of addiction to a technological device and the possible distractions induced by the use of technology. However, he tends not to be concerned about it because he feels supported by personal experience. When in the event of "controlled distraction" technologies went into operation as planned, the danger of an accident was avoided. The prudent user is the one who uses driving aids to feel safer. This can happen due to external conditions that make driving insecure such as, for example, in adverse weather conditions or staying in a queue. There are also personal conditions in which the driver feels, for some reason, at risk, such as driving at night on the highway, very long journeys, queuing or driving in tired conditions. The prudent user uses technological devices as backups or parachutes, to avoid risks due to any personal errors or inappropriate behaviour of other drivers. He tends to welcome the widespread of Advanced Driver Assistance Systems, thinking about benefits to road safety by making driving behaviour uniform and predictable. However, belonging to one or the other category does not depend on the degree of confidence in the technology - that was high in both cases - nor on the process followed to acquire such confidence. The initially fearful user, who acquired confidence by gradually testing technology in different situations and perhaps realizing technical limitations, can prove to be as confident as the experienced one. Similarly, a person who is naturally enthusiastic about technologies and inclined to the introduction of automation, ready to trust immediately, can fall into the category of prudent users.

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AUTHOR CONTRIBUTIONS

Conceptualization, Claudio Lantieri, Valeria Vignali, and Pietro Aricò; methodology, Claudio Lantieri, Valeria Vignali, and Gianluca Borghini; software, Pietro Aricò, Gianluca Borghini, and Gianluca Di Flumeri; validation, Claudio Lantieri, Valeria Vignali, and Paola Lanzi; formal analysis, Margherita Pazzini, Pietro Aricò, Gianluca Borghini, and Gianluca Di Flumeri; investigation, Claudio Lantieri, Valeria Vignali, and Pietro AricÒ; data curation, Ennia Mariapaola Acerra, Margherita Pazzini, Gianluca Borghini, and Gianluca Di Flumeri; writing—original draft preparation, Margherita Pazzini; writing—review and editing, Margherita Pazzini, Claudio Lantieri, and Valeria Vignali; visualization, Fabio Babiloni, Andrea Simone, and Paola Lanzi; supervision, Claudio Lantieri and Valeria Vignali. All authors have read and agreed to the published version of the manuscript.

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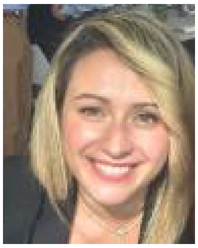

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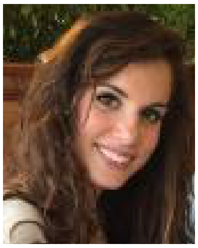

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