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Alcohol effects on drivers' speed management: The influence of visual performance and road complexity

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Abstract

Objective: The aim of this work is to assess how drivers adapt their driving speed as a self-regulation mechanism when driving under the influence of alcohol (DUIA), and the influence of alcohol consumption, visual performance, road complexity, and personal traits.

Method: Thirty one volunteers took part in the study. All of them underwent three experimental sessions: Baseline (no alcohol), Alcohol 1 (low-moderate dose), and Alcohol 2 (moderate-high dose). Vision was tested by means of contrast sensitivity and retinal straylight. Driving performance was assessed using a driving simulator. The difference between the driving speed and the speed limit was calculated in 10 road scenarios of different complexity.

Results: Drivers adapted their driving speed less (i.e., drove faster) in Alcohol 1 condition compared to Alcohol 2 ($p = 0.007$). This indicate that participants felt more confident under the influence of a low-moderate dose of alcohol. Participants with better contrast sensitivity drove faster ($p = 0.021$). The complexity of the road and other factors such as driving experience, gender, or DUIA frequency, also influenced speed choice.

Conclusions: Drivers under the influence of a low-moderate dose of alcohol seem to be less aware of the risk. Contrast sensitivity is a good predictor of the speed choice when DUIA. A better understanding of drivers' behavior under the influence of substance use may be useful to adjust and improve the traffic laws and driving regulations.

Keywords: alcohol use, driving speed, driver self-regulation, contrast sensitivity, road complexity.

1. Introduction

Driving under the influence of alcohol (DUIA) is one of the main causes of road accidents. According to the National Highway Traffic Safety Administration (NHTSA) of the United States Department of Transportation, drunk driving is involved in about 31% of all traffic crash fatalities in the US, concerning blood alcohol concentrations (BACs) over the legal limit for driving in this country (i.e., over 0.08%) (NHTSA, 2021). In fact, a direct relationship has been established between the BAC level and the risk of fatal road accidents (Martin et al., 2017; Voas et al., 2012; Zador et al., 2000).

Driving in a dynamic environment is a complex task that requires the correct integration of different motor, cognitive and perceptual functions. Alcohol negatively affects almost all the psychophysical capabilities necessary for safe driving, including vision, which is responsible for over 90% of the sensory information received by the driver. In this sense, it seems that some visual functions, particularly those related to binocular vision like eye movements or vergences, deteriorate for low BAC levels (Cohen & Alpern, 1969; Goebel et al., 1995; Miller, 1991), while other such as visual acuity or contrast sensitivity are only affected for high BACs (Casares-Lopez et al., 2020; Hill & Toffolon, 1990; Watten & Lie, 1996). Although these visual functions are involved in driving safety, not all of them are included in the standardized driver visual assessment tests. Such is the case with contrast sensitivity, which has been found to be a good predictor of driving performance (Ortiz-Peregrina et al., 2021; Wood, 2002; Wood & Owens, 2005).

So, when vision is impaired, driving abilities could be affected as well. In this regard, it has been observed that visual impairment resulting from alcohol use is associated with a deterioration of the abilities related with driving performance, such as lane keeping, steering behavior or potential hazard detection (Casares-Lopez et al., 2020; Martino et al., 2021). When cognitive, sensorial and motor skills are impaired, drivers tend to adopt a dynamic strategy, known as driver self-regulation, to compensate for the loss of these abilities. Self-regulation practices provides information about driver's self-confidence when facing a driving situation. In case of impaired vision, the most common compensatory mechanisms adopted include a reduction of speed, along with other visual tactical mechanisms, as is the increase of fixations and scanning of the driving scene (Patterson et al., 2019; Wood & Troutbeck, 1992). However, when it comes to substance use, the use of such strategies is not clear. Given that alcohol is a neurodepressant and reduce the responsiveness of drivers to road hazards, drivers could adopt certain strategies that make them feel safer. Even so, the use of these strategies may become more complex when DUIA, since alcohol also impairs the ability to recognize the risk of the task. Thus, different approaches have been observed according to the literature. Some authors hold that drivers under the influence of alcohol often underestimate the negative effects of alcohol on driving (Liu et al., 2021); consequently, a lack of strategies or even a reckless behavior is observed in this situation. On the other hand, a different approach states that drivers reduce their speed as a compensatory strategy when their visual attention is impaired, since they are aware of the danger (Wood & Troutbeck, 1992). As a result, it is not clear whether driving speed is affected by alcohol consumption according to the literature. Most variables related to driving speed (mean speed, maximum speed, acceleration or time taken to complete the route) has shown to be insensitive to behavioral changes induced by alcohol consumption. A review on this topic concluded that mean speed is unaffected by alcohol consumption, but other variables, such as the standard deviation of speed, seem to be more sensitive (Irwin et al., 2017). Charlton and Starkey (2015) observed that participants drove longer over the speed limit only for high alcohol doses (0.08%). Similarly, for high alcohol doses, other authors found an increase in the mean speed, but only in low-complexity scenarios (Vollrath & Fisher, 2017; Martino et al., 2023).

Although driver self-regulation can be practiced at different levels (e.g., avoiding driving, particularly in hazardous situations like substance use) (Gwyther & Holland, 2012; Okonkwo et al., 2007), there is little information about strategies related to operational control when driving under the influence of psychoactive substances (e.g. overcorrecting the position of the vehicle or reducing the speed). On this matter, a previous study on driver self-regulation mechanisms of drivers under the influence of cannabis revealed that cannabis use did not result in self-regulation practices (Ortiz-Peregrina et al., 2023).

On the other hand, the interpretation of the observations related to alcohol impairing effects becomes more entangled, for there are many factors involved. Consequently, even though most studies point toward a deterioration of driving skills after consuming alcohol, results are not uniform. That is because the observed effects depend on the BAC level and, at the same time, the BAC rely on other factors (gender, age, body mass or drinking habits) that interact to induce a certain degree of impairment (Jones & Holmgren, 2009; Maudens et al., 2014; Thomasson, 2002). Also, driving performance is influenced by different factors that determine the quality of the driving and the risk of crashing, like driver's ability and experience, or the road environment. Particularly, the complexity of the road has been demonstrated to have a strong impact on driving performance. In this sense, it has been stated that curved roads and the presence of increased traffic flow lead to a further reduction of speed (Ortiz-Peregrina et al., 2023; Oviedo-Trespalacios et al., 2020). Also, in previous studies it has been shown that driving abilities are more impaired by alcohol when the characteristics of the road are more complex (Casares-Lopez et al., 2020; Vollrath & Fischer, 2017).

Given the important impact of these driver self-regulation mechanisms on road safety, and the lack of consistency regarding the results on the influence of alcohol on driving speed, the aim of this study was to analyze how drivers adapt their speed under the effects of alcohol, and the impact of different factors on self-regulation of driving speed. For that, the influence of alcohol consumption itself, visual performance, other personal traits (gender, driver's experience or the DUIA frequency), and the complexity of the road environment, was assessed.

2. Methods

2.1 Participants

A total of 31 volunteers (16 females and 15 males according to their biological sex) were enrolled in the study (ages 20 to 49 years). Participants were informed about the procedures and a signed consent according to the Declaration of Helsinki was obtained from each of them. The inclusion criteria comprised: being a social drinker, being a regular driver with a valid driving license, not suffering from ocular pathologies, and not consuming drugs that could affect vision. In order to discard alcohol-related disorders, participants took the Alcohol Use Disorders Identification Test (AUDIT), obtaining a score of 8 or less (Babor et al., 2001). All the procedures described in this study were prospectively approved by the University of Granada Ethics Research Committee (921/CEIH/2019).

2.2 Visual assessment

Vision was assessed binocularly and monocularly when possible. For the monocular measurements, one eye was selected at random (Armstrong, 2013).

Contrast sensitivity (CS) was evaluated at 3 m under monocular and binocular viewing conditions with the Pola Vista Vision contrast sensitivity test (DMD MedTech, Villarbasse, Torino, Italy). The test consists of sinusoidal grids with three possible orientations: right, left, or center. Eight different contrast levels were tested for six spatial frequencies (0.75, 1.5, 3, 6, 12, and 18 cycles per degree (cpd)).

The forward scattered light affecting retina, known as intraocular straylight (s), was tested under monocular viewing conditions using the C-Quant straylight meter (Oculus, Optikgeräte GmbH, Germany). This device provides the logarithm of the straylight (log(s)), a parameter that quantifies the veiling luminance over the retinal image resulting from the scattered light in the optical media (van den Berg, 2017). For that, the C-Quant employs the compensation comparison method (Coppens et al., 2006).

2.3 Driving performance

Driving performance was assessed using a fixed-base driving simulator with three high-definition 27-inches screens, along with the software Simax Driving Simulator v.4.0.8 Beta (SimaxVirt S.L., Pamplona, Spain). More information about the simulator can be found elsewhere (Ortiz et al., 2018). Participants had to complete a 12.5 km route, driving through three different road types: 1) a 4.5 km dual carriageway with two lanes in each direction, 120 km speed limit (SL), and mainly straight layout; 2) a 4.7 km mountain road with one lane in each direction, 40 and 90 km/h SL, and winding layout; 3) a 3.3 Km inner-city circuit with 40 and 50 km/h SL, and parked cars in some segments of the circuit. A total of 10 scenarios were selected across the route, featuring different characteristics resulting from varying combinations of road geometry (which refers to road layout and the presence/type of slope) and traffic complexity (including the presence of oncoming cars or other vehicles) (Ortiz-Peregrina et al., 2020). The characteristics of each scenario are represented in Figure 1. A representative length of 100 m was selected in each scenario for analyzing driving performance.

From the 12.5 km general route and from each scenario, the speed adaptation was calculated as the difference between SL and the driving speed. This parameter provides information about the self-regulation of driving speed, indicating if drivers feel more or less confident when driving in a road scenario with specific characteristics (Oviedo-Trespalacios et al., 2017). Therefore, negative values of this variable indicate that the driving speed was higher than the SL, and positive values indicate that participants drove below the SL.

2.4 Alcohol administration and procedure

The alcohol selected for the study was a red wine (13.5 % of alcohol) to create an environment as similar as possible to real-life social drinking. Alcohol administration protocol was established based on previous studies that have used wine as alcoholic beverage (Casares-Lopez et al., 2020; Castro et al., 2014; Munsamy et al., 2016). All participants completed three randomized experimental sessions: a session with no alcohol consumption (baseline), a session after the intake of 300 ml of red wine (Alcohol 1, 32.4 g of alcohol approximately), and a session after the intake of 450 ml of red wine (Alcohol 2, 48.6 g of alcohol approximately). These experimental sessions were preceded by a training session in which participants learned how to use the driving simulator. Alcohol intake was controlled and took place at the laboratory 2h after lunch (between 4pm and 8pm) over a 40-min period (Casares-Lopez et al., 2020; Casares-Lopez et al., 2022).

In the baseline session, the breath alcohol concentration (BrAC, mg/l) was measured before starting the assessment of vision and driving performance using the Dräger Alcotest 6820 breath analyzer (Dräger Safety AG & Co. Lübeck, Germany) to ensure that no alcohol was present in the body. In the experimental sessions with alcohol consumption (Alcohol 1 and Alcohol 2), the device was used 30 minutes after finishing the dose to measure the BrAC reached. Three measurements were made during the experimental session to ensure that the BrAC stayed steady (BrAC level ±

0.05 mg/l). The three BrAC values obtained were then averaged to get a single BrAC value for each participant.

2.5 Statistical analysis

The software SPSS V.26 (SPSS Inc., Chicago, IL) was used to perform the statistical analysis. The normality of the data was tested with the Shapiro-Wilk test. To compare the visual variables (CS and log(s)) and the speed adaptation in the three experimental conditions (baseline, Alcohol 1 and Alcohol 2), a Friedman test was performed, since normality could not be assumed. In addition, a generalized linear mixed model (GLMM) with repeated measures (road scenarios during the three experimental conditions) was performed to analyze the influence of different factors on the speed adaptation (self-regulation of speed). For that, different driver characteristics (driving experience, driving frequency, DUI-alcohol frequency, subjective perception of the influence of alcohol on driving performance and the biological sex), road features (road scenario), and the experimental condition (baseline, Alcohol 1, and Alcohol 2) were selected as factors, and the AUDIT score and the contrast sensitivity were selected as covariates. The significance level was set at 95% for all tests ($p<0.05$).

3. Results

3.1 Personal traits, visual function, and driving performance in the general route

The demographic data of the sample are represented in Table 1. The mean score for driving experience indicates that most of them had more than 5 years of experience. The mean driving frequency showed that most of the participants (20 in total) had driven between 500 and 5000 km in the last year. When they were asked about the driving frequency under the influence of alcohol (DUI-Alcohol- frequency) in the past 12 months, most of them indicated that they had never driven in such circumstances. Finally, with regard to the subjective perception about the impairment when DUI-Alcohol, almost half of the participants thought that their driving skills were affected "quite a lot".

The mean BrAC of the sample in Alcohol 1 condition was below the legal limit for driving in Spain and most of the countries worldwide (0.25 mg/l), while the mean BrAC in Alcohol 2 condition was above the legal limit (Table 2). Considering the visual function, the monocular and binocular contrast sensitivity were reduced following alcohol consumption ($\chi^2(2)=26.50$; $p<0.001$ and $\chi^2(2)=21.87$; $p<0.001$, respectively), in such a way that significant differences were observed between baseline condition and Alcohol 1 and Alcohol 2 conditions (Table 2). Similarly, as shown in Table 2, the straylight increased under the influence of alcohol ($\chi^2(2)=30.06$; $p<0.001$), being such differences significant when comparing the baseline condition to Alcohol 1 and Alcohol 2 conditions. Regarding driving performance, the speed adaptation was different in the three experimental conditions ($\chi^2(2)=8.295$; $p=0.016$). In Alcohol 1 condition, the speed adaptation was more positive than in baseline condition, indicating that participants drove faster under the influence of a low dose of alcohol. For Alcohol 2, however, the speed adaptation was more negative, thus indicating that participants slowed more for a moderate-high dose of alcohol with respect to baseline condition and Alcohol 1 condition. Differences were significant when comparing Alcohol 1 to Alcohol 2 condition, as indicated in Table 2.

3.2 Speed management in different road scenarios

Figure 2 shows the mean value and SD of the speed adaptation for each road scenario in the three experimental conditions. As can be observed in Figure 2.a (speed adaptation in the dual carriageway), participants drove faster, above the speed limit of 120 km/h, in the scenario 1 (dual carriageway, straight). In scenario 2 (dual carriageway, slight bend), the speed adaptation values indicate that drivers slowed down their speed, driving under 120 km/h. No differences were observed in self-regulation of speed between the different experimental conditions (baseline, Alcohol 1, and Alcohol 2) in scenarios 1 ($\chi^2(2)=1.059$; $p=0.589$) and 2 ($\chi^2(2)=2.538$; $p=0.281$).

In the mountain road, for scenarios 3 and 4 (speed limit 90 km/h), participants drove at a speed below the limit (Figure 2.b). In scenarios 5 and 6 (speed limit 40 km/h), participants drove slightly below the limit. In the straight segments with speed limits of 40 and 90 km/h (scenarios 3 and 5), participants self-regulated more for speed in Alcohol 2 condition compared to Alcohol 1, but differences were not significant ($\chi^2(2)=2.600$; $p=0.273$ and $\chi^2(2)=0.521$; $p=0.771$). In the sharp bend segments (scenarios 4 and 6), participants drove faster for both speed limits in Alcohol 2 condition compared to Alcohol 1 and Baseline (Figure 2.b), being such differences significant in scenario 4 ($\chi^2(2)=6.269$; $p=0.044$), but not in scenario 6 ($\chi^2(2)=5.000$; $p=0.082$). As shown in Figure 2.b, in scenario 7, participants drove slower in Alcohol 2 condition compared to baseline and Alcohol 1 conditions, but in Alcohol 1 condition, participants drove faster than in baseline condition ($\chi^2(2)=3.042$; $p=0.213$). In scenario 8, participants drove below the speed limit only in Alcohol 2 condition, but differences with respect to baseline and Alcohol 1 conditions were not significant ($\chi^2(2)=3.042$; $p=0.218$).

Finally, in the inner-city (scenarios 9 and 10), participants drove above the speed limit of 50 km/h, particularly in scenario 10, the segment with no parked cars around (Figure 2.c). In both scenarios, participants in Alcohol 2 condition drove slower than in the baseline and Alcohol 1 conditions, but not significantly ($\chi^2(2)=0.118$; $p=0.943$ and $\chi^2(2)=0.622$; $p=0.733$, respectively).

3.3 The influence of alcohol use, road complexity, and personal traits

A generalized linear mixed model (GLMM) was performed to analyze the influence of different factors on the speed adaptation (self-regulation of speed). The GLMM had a total of 930 data points: 32 subjects x 3 conditions x 10 scenarios. The results of this analysis are shown in Table 3. Regarding the experimental condition, a significant effect was observed, indicating that participants in Alcohol 2 condition slowed down more than in the baseline and Alcohol 1 conditions. The road scenario also had a significant influence on the speed adaptation; according to the estimates, in scenarios 1 and 2 (dual carriageway), participants drove slower than in the reference category (scenario 10). Also, in scenarios 5, 6, and 8 (mountain road), which presented more curves and slopes, participant drove slower. Finally, participants also slowed down more in scenario 9, corresponding to inner-city circuit (just like the reference category, scenario 10), since parked cars were present in this scenario.

The driving experience also was a significant predictor of the driving speed, indicating that less experienced drivers drove faster. Contrary, the driving frequency had no significant influence on driving speed. The DUI-Alcohol frequency also influenced how drivers regulated their speed, in such a way that participants who drove once under the influence of alcohol in the last year, drove slower than those who drove thrice under these conditions. Their subjective perception about how alcohol affects driving also predicted the self-regulation of speed, indicating that participants who though that drinking alcohol does not affect driving at all, drove faster than those who are more aware about the negative influence of alcohol on driving. The drinking habits, assessed by means of the AUDIT, showed a significant influence on the speed adaptation, in such a way that participants with higher scores (a more frequent use of alcohol) slowed down more.

With respect to visual function, binocular contrast sensitivity (CS) was a significant predictor of the driving speed, with higher values of CS being associated to higher speeds. Finally, when addressing the influence of biological sex, a significant effect was observed, indicating that males drove faster.

Discussion

The purpose of this study was to assess the impact of alcohol intake (two different doses) on self-regulation of driving speed, as well as the influence of different factors (including alcohol consumption and visual function) on speed management. First, we assessed the how vision changed under the influence of alcohol, particularly contrast sensitivity and retinal straylight. These two visual functions are related, since intraocular scattered light reaching retina (responsible for the retinal straylight) causes a deterioration in image contrast (van den Berg, 2017). In this sense, it has been reported that, in the presence of forward scattered light, contrast sensitivity deteriorates (Palomo-Alvarez & Puell, 2015; Puell & Palomo-Alvarez, 2017). Visual outcomes indicated a deterioration of contrast sensitivity (monocular and binocular) following alcohol intake, which was greater for the highest amount of alcohol (Alcohol 2). Similar results have been reported before, particularly for high alcohol doses (Casares-Lopez et al., 2020; Pearson & Timney, 1998). Alcohol is a psychoactive substance that affects the autonomic nervous system, which control multiple visual functions, such as the accommodation process and the pupil size (Gilmartin, 1986; McDougal & Gamlin, 2015). Also, alcohol interferes with the optic nerve and the parvocellular pathway, which has been suggested to be responsible for the deterioration of the contrast sensitivity for low and high spatial frequencies, respectively (Zhuang et al., 2012). On the other hand, retinal straylight, due to the intraocular scattered light, increased following alcohol consumption, particularly for Alcohol 2 condition. Alcohol is known to alter the stability of the tear film. It has been suggested that these changes in the tear film, along with an increase of the pupil size, may be responsible for the deterioration of the retinal image quality and the increase of the intraocular scattering (Castro et al., 2014). Similarly, other authors have reported before an increase of night vision disturbances and intraocular scattering under the influence of alcohol, especially when the BrAC level is above the legal limit for driving (0.25 mg/l) (Casares-Lopez et al., 2021; Castro et al., 2014).

Regarding driving performance, we found that participants adapted their driving speed more under the influence of a high amount of alcohol (Alcohol 2) compared to a lower amount of alcohol (Alcohol 1), but no differences were observed with respect to baseline condition. The influence of alcohol on other metrics related to driving speed, particularly lane keeping, is well established; lane keeping is one of the most sensitive variables to alcohol intake, in such a way that the distance driven outside the lane increase for low, high and moderate doses (Berthelon & Gineyt, 2014; Casares-López et al., 2020; Charlton & Starkey, 2015). The impact of alcohol on speed management, however, is not that clear. It has been shown that slowing down driving speed is a behavior often adopted as a compensatory mechanism when drivers feel less confident, which would indicate that participants under the influence of moderate-high BrAC levels would feel more unsafe than when driving under the effects of low-moderate BrAC levels. Even though a higher alcohol rate (BAC over the legal limit for driving) is associated to a worse driving performance (Casares-Lopez et al., 2020), participants demonstrated to be aware of the complexity of the situation when driving under a high dose of alcohol. Although no consensus seems to be reached on this issue in the literature, similar results have been reported by Vollrath and Fisher (2017), who observed that drivers under the effects of alcohol slowed down their speed. Alcohol tolerance may also be responsible for these findings. According to these authors, highly intoxicated drivers adopt this compensatory behavior to try to seem sober to observers and, consequently, they adapt their driving style to avoid road hazards (Vollrath & Fischer, 2017).

A different approach holds that speed control is less sensitive to impairment at low-moderate BrAC levels compared to other aspects of driving performance, such as lane keeping or the control of the steering wheel (Martin et al., 2013). In this sense, other authors have observed a lack of strategies to compensate for the complexity of the driving task, since no significant effects of alcohol on driving speed were found (Harrison & Fillmore, 2011). Also, a previous study that analyzed driving performance under the effects of alcohol for similar BrAC levels (BrAC<0.25 and BrAC≥0.25 mg/l), revealed no significant differences in driving speed with respect to baseline condition (Casares-Lopez et al., 2020). On the other hand, different authors have reported an increase in driving speed under the effects of alcohol, indicating that drivers behave recklessly under these conditions. Thus, Charlton and Starkey found that participants drove more time above the speed limit for blood alcohol concentrations (BAC) of 0.05% and 0.08% (equivalent to BrAC levels of 0.25 and 0.40 mg/l, respectively), driving at faster speeds (Charlton & Starkey, 2015). Similarly, Yadav and Velaga observed an increase of the driving speed under the influence of different alcohol levels (BACs of 0.03%, 0.05%, and 0.08%, equivalent to BrAC levels of 0.15, 0.25, and 0.40 mg/l, respectively) (Yadav & Velaga, 2020).

It is noteworthy that we observed an increase of the driving speed, but only when participants were under legal limit for driving (BrAC<0.25 mg/l). The absence of significant effects of alcohol on driving speed or the increase of speed observed under the influence of alcohol, as is the case, may indicate that drivers overestimate their driving abilities in such circumstances. This behavior could pose a problem, since vision and other motor and cognitive skills that are involved in driving performance are impaired at low BACs (Casares-Lopez et al., 2022; Hindmarch et al., 1992).

These different approaches and contradictory results in the literature indicate that the management of speed under the influence of alcohol may depend not only on the amount of alcohol consumed, but also on other factors. Thus, the generalized linear mixed model performed in this study showed a significant influence of different factors on speed management. As expected given the results obtained in the pairwise comparisons, the experimental condition (i.e., alcohol consumption) had a significant influence on driving speed, but differences were observed only when comparing Alcohol 1 and Alcohol 2 conditions. The complexity of the road scenario also had significant influence on speed management. When comparing scenario 10, used as the reference category (city, no parked cars, 50 km/h SL) with the scenarios in dual-carriageway and mountain road, we observed that participants self-regulated more their speed in scenarios corresponding to straight (scenarios 1 and 5) and curved road segments (scenarios 2 and 6). Although previous works reported a further reduction of speed in curved roads (Oviedo-Trespalacios et al., 2017; Vollrath & Fischer, 2017), such findings were not observed in this study. These results could be explained by the fact that the straight segments in the mountain road were located between two sharp bends. Also, there are other factors that have an influence speed choice in curved roads, such as signing (Kanellaidis, 1995). The lack of curve-warning signs in the road, as is the case of the scenarios analyzed in this study, may be responsible for the maintenance of the speed in straight and bend segments. In mountain road, participants self-regulated more for speed in scenarios with 40 km/h SL and less in scenarios with 90 km/h SL. Also, according to Figure 2, it can be observed that in scenarios with 50 and 90 km/h SL, participants drove above the SL. Similarly, other studies have observed a lack of SL compliance in roads with 50 km/h and 90 km/h (Aberg et al., 1997; Haglund & Åberg, 2000). These observations could indicate that the speed choice may also be associated with the speed limit in complex road scenarios, although this issue needs to be studied further. In this sense, some authors have stated that speed choice is associated with driver's risk perception (influenced by the environment) rather than speed limits (Wilmot & Khanal, 1999); however, these two aspects are often related. Contrary, it is noteworthy that, despite the simplicity of the dual carriageway (120 km/h SL) with respect to the other two sections with lower SL (mountain road and inner-city), drivers self-regulated more for speed in scenarios 1 and 2 compared to the reference category (scenario 10), maybe because they feel more comfortable when driving under the SL. In fact other authors stated that, in normal conditions, drivers chose their speed according to their usual speeds, which are usually the speeds drivers feel more comfortable at, rather than the speed limits (Ahie et al., 2015).

Factors other than the complexity of the road were also analyzed. Visual performance, particularly contrast sensitivity, also influenced the selection of driving speed. Thus, participants with better contrast sensitivity drove faster than those with a poorer contrast detection. Previous studied had showed the importance of this visual function on driving performance (Casares-Lopez et al., 2020; Kimlin et al., 2017; Owsley & McGwin, 2010), as contrast sensitivity allows to distinguish road marks and hazards, particularly when the conditions of the road are not favorable. Regarding self-regulation of speed, other authors have demonstrated that contrast sensitivity impaired by cannabis use has an impact on driving speed (Ortiz-Peregrina et al., 2023). On the other hand, as shown the pairwise comparisons analysis, contrast sensitivity is impaired by alcohol. Given the importance of this visual function for driving performance in general, and also for driver self-regulation, the deterioration of contrast sensitivity seems to contribute to the driver's feeling of insecurity, leading to a decrease in driving speed as a compensatory strategy.

According to the results obtained in the GLMM, the driving experience is also a factor influencing speed management, in such a way that more experienced participants adapted their driving speed more, selecting speed further below to the speed limit. These results may be closely related to speed estimation, given that it has been observed that less experienced drivers tend to underestimate the speed as driving speed increases (Wu et al., 2017). Also, the biological sex was a predictor of driving speed selected. Previous studies have shown that speed estimation is worse for females, and that males adjust their driving speed better than female (Wu et al., 2017). Contrary, our results indicated that females drove slower, driving closer to the SL. Similarly, other authors have reported that females are more cautious when driving, as they travel at lower speeds and impose more restrictions when their visual attention is impaired (Hiang & Ming, 2015; Okonkwo et al., 2007). Notwithstanding, it seems that gender differences observed in simulated driving may not be applicable to real driving, as suggested by Coluccia and Louse (2004), and thus, these results should be interpreted with caution.

4. Conclusions

Participants drove above the speed limit in the three experimental conditions: baseline, Alcohol 1 (low-moderate alcohol dose) and Alcohol 2 (moderate-high alcohol dose), particularly in Alcohol 1 session. The increase of the driving speed when driving under the influence of a low-moderate dose of alcohol (Alcohol 1, mean BrAC<0.25 mg/l) could indicate that, in these conditions, participants feel more confident. This means that drivers are less aware of the risk, thus adapting their driving speed less (in this case, driving faster). However, it seems that alcohol intake by itself would not be determining factor in speed choice. The speed adaptation is influenced by factors other than alcohol consumption, including visual performance among them. Thus, participants with lower contrast, self-regulated more for speed. Regarding the road environment, we observed that the SL of the road scenario, along with other characteristics like the road layout, the traffic flow, or the presence of parked cars in the city, influence the selection of driving speed. Other factors, like driving experience, gender and DUIA frequency influenced driver self-regulation. Therefore, it seems that contrast sensitivity is a good predictor of self-regulation strategies in terms of operational control (speed reduction). However, the involvement of alcohol use and visual performance on other self-regulation practices remains to be analyzed in the future. Also, a further study on the influence of specific road characteristics, particularly speed limits, needs to be conducted.

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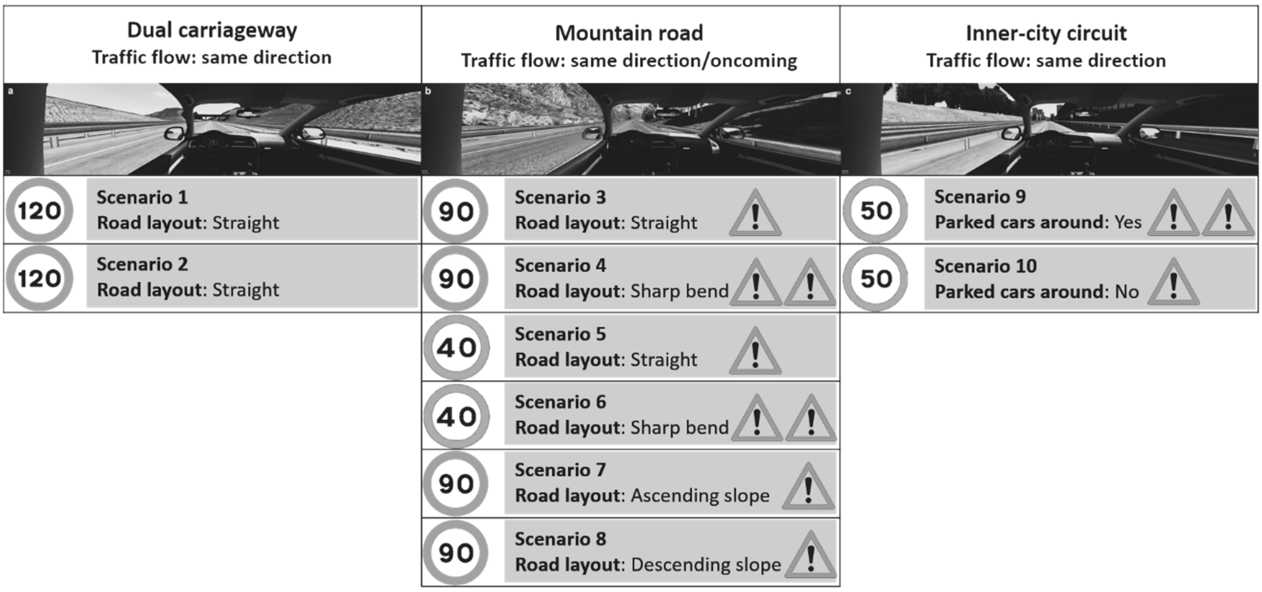

Dual carriageway
Traffic flow: same direction
Mountain road
Traffic flow: same direction/oncoming
Inner-city circuit
Traffic flow: same direction
120
Scenario 1
Road layout: Straight
120
Scenario 2
Road layout: Straight
90
Scenario 3
Road layout: Straight
90
Scenario 4
Road layout: Sharp bend
40
Scenario 5
Road layout: Straight
40
Scenario 6
Road layout: Sharp bend
90
Scenario 7
Road layout: Ascending slope
90
Scenario 8
Road layout: Descending slope
50
Scenario 9
Parked cars around: Yes
50
Scenario 10
Parked cars around: No

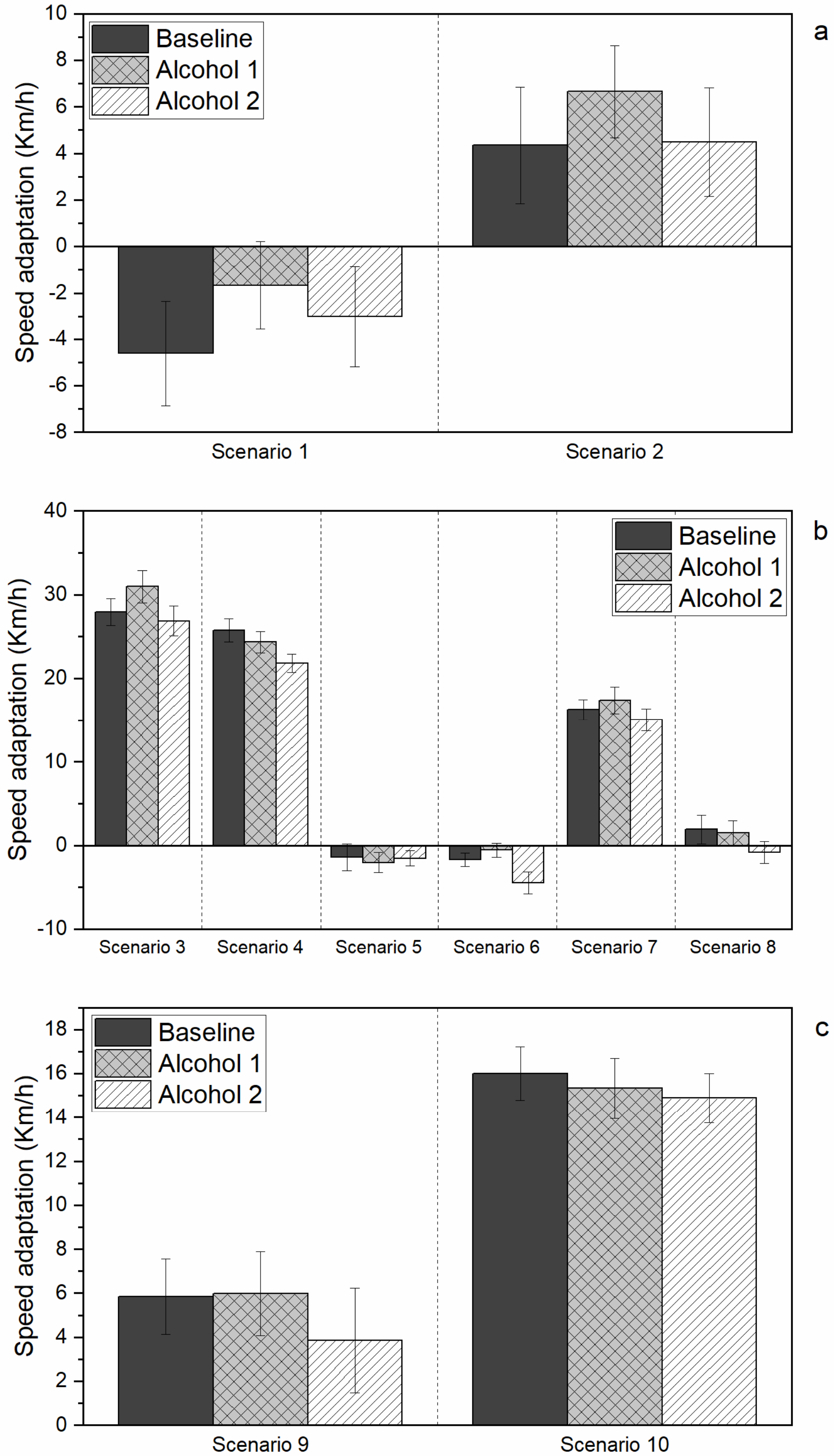
a
Speed adaptation (Km/h)
Baseline
Alcohol 1
Alcohol 2
10
8
6
4
2
0
-2
-4
-6
-8
Scenario 1
Scenario 2
b
Speed adaptation (Km/h)
40
30
20
10
0
-10
Scenario 3
Scenario 4
Scenario 5
Scenario 6
Scenario 7
Scenario 8
c
Speed adaptation (Km/h)
18
16
14
12
10
8
6
4
2
0
Scenario 9
Scenario 10

Figure captions

Figure 1. The different scenarios analyzed (1 to 10) in the three sections (dual carriageway, mountain road and inner-city circuit) and their characteristics. The warning signs represent the difficulty level of the road scenarios: 0 = low; 1 = medium; 2 = high.

Figure 2. Mean speed adaptation and the SD in the different road scenarios (10 in total) for the three experimental conditions: baseline, Alcohol 1, and Alcohol 2. Panel “a” shows results from dual carriageway, panel “b” shows results from mountain road, and paner “c” shows restlts from inner-city circuit.

Table 1. Age of the sample and scores of the AUDIT and different questions (mean value ± SD). The number of responses for each option of the question, as well as the percentages, are also included.

Age	27.0 ± 6.7
AUDIT score	4.1 ± 2.1
Driving experience	3.0 ± 1.0
0 = Less than 1 year	0 (0%)
1 = Between 1 and 3 years	3 (10%)
2 = Between 3 and 5 years	7 (23%)
3 = Between 5 and 10 years	11 (35%)
4 = More than 10 years	10 (32%)
Driving frequency	1.5 ± 1.0
0 = Less than 500 km	6 (19%)
1 = Between 500 and 1000 km	9 (29%)
2 = Between 1000 and 5000 km	11 (35%)
3 = More than 5000 km	5 (16%)
In the past 12 months, how often have you driven within two hours of drinking alcohol? (DUI-Alcohol frequency)	0.6 ± 0.9
0 = Never	19 (61%)
1 = Once	8 (26%)
2 = Twice	2 (6.5%)
3 = Thrice	2 (6.5%)
4 = More than 3 times	0 (0%)
Do you consider that your driving skills are negatively affected following alcohol consumption? If you have never driven under the effects of alcohol, please answer how you think it would affect your driving skills	2.5 ± 1.0
0 = Does not affect at all	2 (6.5%)
1 = Affects slightly	2 (6.5%)
2 = Affects a bit	9 (29%)
3 = Affects quite a lot	14 (45%)
4 = Affects a lot	4 (13%)

Table 2. Mean values (± SD) of the BrAC, the speed adaptation considering all the scenarios studied, and the visual variables in the three experimental conditions: baseline (B), Alcohol 1 (A1), and Alcohol 2 (A2). The p-value resulting from the pairwise comparisons are also included.

	Baseline (B)	Alcohol 1 (A1)	Alcohol 2 (A2)	p-value
BrAC (mg/l)	--	0.18 ± 0.08	0.29 ± 0.11	--
Monocular CS	125.26 ± 18.20	108.80 ± 19.09	102.16 ± 18.87	B-A1: 0.003 B-A2: <0.001 A1-A2: 0.162
Binocular CS	153.42 ± 11.87	140.46 ± 20.83	137.51 ± 21.63	B-A1: 0.013 B-A2: <0.001 A1-A2: 0.547
log(s)	0.87 ± 0.10	0.93 ± 0.14	0.98 ± 0.14	B-A1: 0.005 B-A2: <0.001 A1-A2: 0.229
Speed Adaptation (km/h)	8.80 ± 14.54	9.59 ± 14.44	7.17 ± 14.08	B-A1: 1.000 B-A2: 0.082 A1-A2: 0.007

Table 3. Results of the generalized linear mixed model. The coefficients, the standard deviation (SD), the t-statistic, the p-value and the confidence interval (CI) are reported. For the comparisons between the different categories of each factor included in the model, the last category was selected as reference.

	Coefficient	**SE**	**t-statistic**	**p-value**	**95% CI**
Experimental Condition					
Baseline	1.28	0.71	1.787	0.075	[-1.13, 2.68]
Alcohol 1	2.24	0.63	3.541	0.001**	[1.00, 3.48]
Alcohol 2	-	-	-	-	-
Road scenario					
Scenario 1: Dual carriageway, straight, 120 km/h SL	-18.08	1.34	-13.448	<0.001**	[-20.74, -15.42]
Scenario 2: : Dual carriageway, Slight bend, 120 km/h SL	-10.27	1.43	-7.168	<0.001**	[-13.10, -7.43]
Scenario 3: Mountain, straight, 90 km/h SL	13.47	1.21	11.088	<0.001**	[11.06, 15.87]
Scenario 4: Mountain, sharp bend, 90 km/h SL	8.85	0.93	9.503	<0.001**	[7.01, 10.69]
Scenario 5: Mountain, straight, 40 km/h SL	-15.49	1.01	-15.316	<0.001**	[-17.49, -13.49]
Scenario 6: Mountain, sharp bend, 40 km/h SL	-16.51	0.88	-18.700	<0.001**	[-18.25, -14.76]
Scenario 7: Mountain, straight, ascending, 90 km/h SL	1.24	0.97	1.272	0.205	[-0.69, 3.16]
Scenario 8: Mountain, straight, descending, 90 km/h SL	-13.81	1.15	-12.022	<0.001**	[-16.08, -11.54]
Scenario 9: City, straight, parked cars, 50 km/h SL	-10.11	1.24	-8.149	<0.001**	[-12.57, -7.66]
Scenario 10: City, straight, no parked cars, 50 km/h SL	-	-	-	-	-
Driving experience					
Between 1 and 3 years	4.18	1.28	3.271	0.001*	[1.67, 6.69]
Between 3 and 5 years	3.40	1.22	2.773	0.006*	[0.99, 5.80]
Between 5 and 10 years	-3.25	0.88	-3.684	<0.001**	[-4.98, -1.52]
More than 10 years	-	-	-	-	-
Driving frequency (in the last 12 months)					
Less than 500 km	-1.60	1.53	-1.051	0.294	[-4.60, 1.39]
Between 500 and 1000 km	-1.37	1.38	-0.992	0.321	[-4.09, 1.34]

Between 1000 and 5000 km	-3.25	1.29	-3.694	0.367	[-1.37, 3.70]
More than 5000 km	-	-	-	-	-
DUIA frequency (in the last 12 months)					
Never	-0.32	1.58	-0.202	0.840	[-3.42, 2.78]
Once	-3.60	1.68	-2.150	0.032*	[-6.89, -0.31]
Twice	2.57	1.78	1.440	0.151	[-0.93, 6.06]
Thrice	-	-	-	-	-
Subjective perception of the influence of alcohol on driving performance					
Does not affect at all	7.49	1.54	4.861	<0.001**	[4.47, 10.51]
Affects slightly	4.84	1.75	2.765	0.006*	[1.40, 8.28]
Affects a bit	3.37	1.15	3.302	0.003*	[1.12, 5.62]
Affects quite a lot	2.52	1.09	2.322	0.021*	[0.39,4.65]
Affects a lot	-	-	-	-	-
AUDIT score	-1.07	0.18	-5.913	<0.001**	[-1.43, -0.72]
Binocular CS	0.03	0.02	2.322	0.021*	[0.39, 4.650]
Biological sex					
Male	3.64	1.07	3.404	0.001*	[-1.539, 5.74]
Female	-	-	-	-	-
Intercept	10.42	2.88	3.623	<0.001**	[4.77, 16.07]
Aikake information criterion	6308.10				
Bayesian information criterion	6450.91				

*p<0.05; **p<0.001