Driving Risk Assessment Under the Effect of Alcohol Through an Eye Tracking System in Virtual Reality

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Abstract. The issue of driving under the effect of alcohol is a matter of several studies in the field of road safety because today alcohol is widely diffused especially among very young people (age ranging between 18 and 25). Each year data provided by authorities are worrying, more than a third of the accidents registered in European countries are caused by alcohol. Italy is aligned with this trend; the ISS – National Institute of Health estimates that alcohol-related road accidents are equal to 30–35% of the total road accidents. Medical researches confirm that alcohol generates negative effects on driving, impairs the ability of perception, attention, processing and evaluation and it has negative effects on cognitive and motor skills. Therefore, the present research is developed in the field of a wider project research with the purpose to investigate and estimate the impact of alcohol on road safety to support awareness campaigns "Drink or Drive". As demonstrated by findings of the previous study, alcohol has a significant impact on driving performances in terms of geometric, kinematic and dynamic measures. Trajectory, stopping and overtaking maneuvers were studied and a significant delay in reflexes, especially in stopping and overtaking maneuvers, that exposes drivers to high risk level, was calculated. In this research, the focus is on the drivers' eye-movements that are recorded in the virtual reality driving experiment. To understand how much alcohol impairs attention and concentration in relation to the driving performances, these data are processed and two eye blinking measures (i.e. % blinking and blink rate) are analyzed A sample of 20 drivers were requested to drive the virtual reality-driving simulator situated in the LASS3 Virtual Reality Laboratory of University Research Centre for Road Safety. The route runs in extra-urban and urban areas, in order to study drivers' behavior in different cases and subjecting drivers to different stimuli (i.e. pedestrian crossing, overtaking maneuver, sudden braking, etc.). The results are a comparison between the results of two conditions drunken and sober. Results show that alcohol affects attention and concentration increasing the absolute value of blinking and its rate. During the stopping and the overtaking maneuvers where driving measures show higher risk levels in drunkenness condition respect the to the sober one, eye measures show a reduction in blinking and frequency (in both conditions) on behalf of a more attention to the road.

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1 Introduction

Alcohol affects different brain functions and impairs the capabilities of perception, attention, processing and evaluation. It is identified as the most important human factor altering risk perception with consequences on road safety [1]. Alcohol involve every year many people in driving accidents, especially young people. Data provided by European Commission [2] show that 96% of people involved in accidents are men, of which 33% young with an age between 15 and 24 years. Young people are the most affected by this custom and often, for the unconsciousness due to age, they reach higher values of Blood Alcohol Concentration (BAC) level are the most involved in alcohol-related accidents [3].

The statement of the problem seems very worrying; hence, there are many awareness campaigns promoting a consciousness of drink and drive, as in this French case of study [4]. To date, in Italy, the legal BAC limit is 0.5% (0.0% for novice drivers), over this value, the suspension of the license is expected for the offenders, over 0.8% there is the detention up to six months [5].

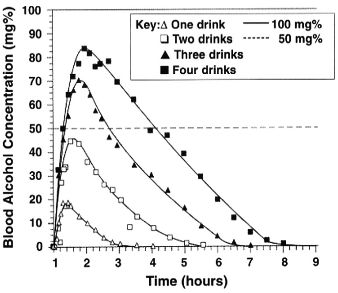

Fig. 1. Curve of BAC (Blood Alcohol Concentration %)

The achievement of these values is subjective and depends on the diffusion of alcohol in the body (Fig. 1.), that is related to bodily and biological parameter (e.g. weigh, gender, age), to the amount of alcohol drunken and to the time elapsed since the assumption. The first negative effects appear already with a value of 0.2 BAC in terms of the ability to divide the attention between two or more sources of information, at a value of 0.5 BAC the peripheral view is compromised, reaction times increase, and psychomotor coordination begin to be compromised. Reaching 0.8 BAC, the previous symptoms get worse until with 1 BAC when the peripheral view is strongly compromised, as well as the perception of the distances and the speed [6, 7, 8].

Therefore, it is clear how these effects have a significant impact on the driving skills and several studies have studied this issue. In detail, alcohol assumption represents a hazard for road safety not only because impairs the driving risk perception, but also because it reduces the perceived negative consequences of risk-taking [9] and alters decision-making while driving. Then, who drives under the effect of alcohol is not aware of exposing himself and the other users of the road to high risk [10, 11].

As literature review shows, effects of alcohol on driving skills involve different cognitive and motor impairments (e.g. eye and body) could be examined and calculated in a variety of ways by means of different kinds of measures on driving performance [12] or on psychophysiological effects. This study is a part of a project research that aims to investigate the effects of alcohol on driving by monitoring different parameters of driving behaviour. The first study developed by the authors [13] has investigated the kinematic and dynamic measures to estimate the decay in driving performance in impaired psychophysiological condition. In the same virtual reality driving experiment, the present paper aims to analyze the eye-movements, recorded by an eye tracking system, in order to estimate the blinking measures to correlate them with the results of the previous study.

As mentioned in the literature review, blinking is a semi-automatic action of the eyelid necessary just to keep the eye lubricated. Blinking measures both cognitive and visual distraction and it depends on the cognitive workload [14]. Results of a study aims to investigate eye-movements during a lane changing task [15] show that with the increasing of workload, increases the blinking value in comparison with the track where there is low cognitive workload. Blinking is also related to the psychophysiological condition of the driver. In fact, it is a reliable indicator of drowsiness and fatigue [16] and, in this regard, it allows to understand how much the effect of alcohol affect the drivers' behaviour in terms of drowsiness and lassitude during a driving task.

Blinking is a bodily function that involve the eyelid in a rapid close of the eye to lubricate the eye. Medical researchers [17] have found that the duration of blink and its rate are related to attention and concentration and are reliable indicators of tiredness, drowsiness and lassitude. Therefore, the research question could be: is it possible to correlate the eye measures with the driving performances measures to understand the alcohol-related accidents phenomenon?

2 Aim of Study

In the field of this literature review, the present research is developed with the purpose to assess the effect of alcohol on the driving capabilities using an eye tracking system in a virtual reality driving environment. Therefore, the results of the eye-movements will be compared with the previous results of the driving performance in order to understand how much are different the driving performance and the eye-movements of drivers in drunken condition.

3 Method

3.1 Eye Tracking System

The eye tracker is the tool to study the eye-movements and the position of the gaze. The eye tracking system of the LASS3 - Virtual Reality Laboratory of University Research Centre for Road Safety - is made up of a camera, fixed on the dashboard of the vehicle that records the face of the driver during the virtual reality driving test. Therefore, the outcome is a recording of the driver face during the driving task.

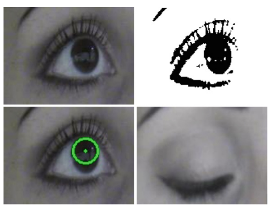

Fig. 2. Processing of the image analysis algorithm

Image Analysis Algorithm

Video is processed with an ad hoc image analysis algorithm (Fig. 2.) in order to carry out the outcome measures of blinking and frequency. The proposed algorithm detects the eye-movements starting from a sequence of images of the driver face, converted in binary images by means of a RGB threshold. For each frame the code scans the face of the driver to find the search-space around the eyes. During the tracking, the search-space decreases to the area corresponding to the eye-envelopes. When an area with a percentage of black pixels over a fixed threshold (i.e. pupil) is found, it recognizes the eye as opened, otherwise the eye is considered closed. The algorithm records the percentage of opened and closed frames weighted on the total of the images and the frequency of closed frame in time.

The reliability of the algorithm is highly dependent on the quality of the image in terms of lighting condition. In fact, the light contrast of the raw image is the main variable that may affect the RGB threshold and consequently the black pixels recognition. During a driving test, the light of the room is switched off and the lighting condition of the pictures depends on the light of the simulated scenario. Therefore, the RGB threshold during the tracking must be checked in order to set the most suitable value for the current light condition.

3.2 Driving Simulator

The driving simulator of LASS3 is a Toyota Auris (Fig. 3), converted in a driving simulator by removing all unnecessary parts and integrating with the components that will communicate with the workstation computer, equipped with the software STISIM DRIVE®. With three high-tech projectors, a wide image in front of the car and sideways is projected in order to cover a visual angle of 180°. In addition, the sound speakers are located in the hood of the car in order to emulate the acoustic road environment at the best. The outcome measures of the simulation tests are 45 parameters recorded with a frequency equal to 0.25 s.

Fig. 3. STISIM DRIVE® driving simulator of LASS3

Driving Scenario

The same scenario of the previous study is implemented and tested by a sample of drivers. The two different environments: urban and extra-urban are characterized as described in Table 1.

Table 1. Characterization of two road environment

Area	Analysis	Lanes	Shoulder	Speed limit	Description
Urban	Baseline Stopping maneuver	3.50 m	–	50 km/h	Intersections, pedestrian crossing, parking vehicle on the roadside, overtaking maneuvers is not allowed
Extra-urban	Baseline Overtaking maneuver	3.50 m	1.00 m	90 km/h	No intersection, no pedestrian crossing, no parking vehicle, overtaking maneuvers allowed

Baseline measures are recorded in the tracks of the ride at rest without event (in both areas) could affect the physiological parameters. In the urban area, many sudden events are built to induce the stopping maneuver, as well in the extra-urban area slow vehicle lead drivers to overtake.

In addition, to increase the accuracy of the virtual reality environment, a value of Level of Service (LOS) is determined. This value corresponds to a travel speed defined as a percentage of base Free-Flow Speed (FFS). According to Highway Capacity Manual (HCM), with a travel speed of 35–40 km/h in an urban area characterized as described above and a FFS of 50 km/h, the corresponding LOS value is B. In the extra-urban area with the same LOS a traffic density equal to 7 vehicle/km is defined.

3.3 Participants

To twenty participants (10 women and 10 men, 35 years old on average ranging from 26 to 50 years) of the driving sample of the previous study, the eye-movements are recorded. The sample is recruited via advertisings as volunteers from the Department of Engineering at the University Roma Tre and is tested is in LASS3. All subjects were required to have a driving license for at least 1 year.

At the beginning, after the reception in the laboratory, they are informed about the procedure of the test in terms of duration, use of drivers control and knowledge of the tool. They have also completed a questionnaire with personal information and then they are requested to complete a training scenario for at least 10 min in order to get confident with the tool. In order to assure to select a homogenous sample of drivers to avoid biasing of the results induced by driver attitude, experience, age and gender out other neuro-cognitive factors [13], a statistical criterion is applied. Chauvenet criterion [18] allow to assess if the sample, in terms of number of subjects, is significant from a statistical point of view, so assuring a correct interpretation of the results. According to Chauvenet criterion one driver is excluded to the analysis due to anomalous behaviours in terms of speed (data are considered outliers if the speed values were strongly higher or lower than the mean), therefore the data processing is based on 19 drivers.

3.4 Procedure

After the training test, the drivers were requested to perform the scenario in sober condition to record the baseline ride to compare it with the results of the drunken condition. Afterwards, a very careful procedure of a virtual reality driving experiment was required to administer alcohol to the participants. Subjects were instructed to abstain from food and smoke (for 4 h before), caffeine and alcohol (for 36 h before) to avoid biasing the effects of the alcohol administration [1].

The threshold of alcohol, calculated in BAC, we chose to test is equal to 1. For each participants the amount of alcohol to reach 1 BAC was calculated in function to different body parameter (e.g female, male, weigh, height, etc.) with the Widmark formula (1) described as follow and in Table 2.

$$BAC = \frac{A \times Sw_{blood}}{r \times W} - \xi \times t \tag{1}$$

Table 2. Parameter of Widmark formula

Parameter	Description
A	Weight of the amount of alcohol (grams)
S_w	Specific weight of the blood that is fixed equal to 1.055 (N/m^3)
W	Weight of the driver (Kg)
r	Widmark factor that allow to convert W to liters of blood that the body contains and it depends on gender (equal to 0.73 for men and 0.66 for women)
ξ	Decay ratio of the drunkenness equal to 0.015 (1/minutes)

The amount of alcohol in grams (A) comes out easily from the inverse of the formula.

The alcohol level is monitored by a breath analyzer, that measures the alcohol concentration in the air emitted with the breath. BAC is measured for the first time 10 min after the end of administration and then at regular intervals to monitoring the alcohol absorption and built the alcohol curve for each participant. In this way, it was possible to understand when each subject had reached a BAC level equal to 1 to start the driving test and assure that this level is constant for all the time of the test drive. After the test, subjects are seated in the laboratory waiting area until the end of the session, where some drinks and snacks were offered. During this period the level of BAC is measured at 30 min intervals until the end of the session (e.g. BAC < 0.5 g/L).

3.5 Indicators

Eye-Movements Measures

As mentioned in the literature review, blinking is a semi-automatic action of the eyelid necessary just to keep the eye lubricated. Blinking measures both cognitive and visual distraction and it depends on the cognitive workload [14]. Results of a study aims to investigate eye-movements during a lane changing task [13] show that with the increasing of workload, increases the blinking value in comparison with the track where there is low cognitive workload. Blinking is also related to the psychophysiological condition of the driver. In fact, it is a reliable indicator of drowsiness and fatigue [16] and, in this regard, it allows to understand how much the effect of alcohol affect the drivers' behaviour in terms of drowsiness and lassitude during a driving task. From a numerical point of view (2), the algorithm calculates blinking values as the ratio between the closed frames on the total frames. It means the percentage of the closed frames that result in the time that the driver spent with closed eyes during the driving task with consequently affection on road safety.

$$Blinking = \frac{N^{\circ}\, closed\, frames}{N^{\circ}\, total\, frames} \times 100 \tag{2}$$

The blink frequency, instead, is the blink rates in time; it means how many times the driver closes the eyes in the period referred to the simulated scenario. The combination of these two indicators could be useful to understand how much alcohol affects the driving behaviour in terms of drowsiness, fatigue and lower risk perception, than in sober condition.

3.6 Anova Test

A statistical validation of the outcome measures of the processing data is required in order to generalize the results. According to findings in literature [19] the analysis of variance test (ANOVA) is applied in order to highlight that the values differences into two groups (sober and drunken) for each indicator depend on the two psychophysiological condition and not on the chance. Starting from the postulate that the average of the dependent variable (i.e. eye-movements indicators) is the same for the two sample (null hypothesis), rejecting the null hypothesis would mean that the independent variable (i.e. sober or drunken condition) influences the dependent variable and the results are reliable. For each parameter, two analyses are performed: the first to evaluate the effects due to the psychophysiological condition and the second to investigate the effects of different scenario, namely type of analyzed maneuver. The results of ANOVA test will be show in the following section Results and Discussion.

4 Results and Discussion

The data analysis of the eye-movements aims to study the differences in blinking and its frequency between sober and drunken conditions in order to estimate how much alcohol affect the drivers' behaviour in terms of risk perception during the driving task. Data analysis is processed before to find the baseline values of blinking and frequency for each driver and then focusing on stopping and overtaking maneuvers to compare it with the previous results of driving performances [13]. The baseline is estimated considering the tracks of the ride at rest without event could affect the physiological parameters, while in the other two situations the length of maneuvers is determined. For the stopping maneuver, the length of analysis is from the point of release to the point with speed value equal to zero; instead, for the overtaking maneuver from the point when the driver crosses the centerline to perform a lane changing to the specular point at the end of the same maneuver.

4.1 Statistical Analysis

As mentioned before, for each parameter (blinking and frequency), two analyses are performed: the first to evaluate the effects due to the psychophysiological condition (sober and drunkenness) and the second to investigate the effects of different scenario, namely type of maneuver.

As statistical results show (Table 3), blinking values depend both on psychophysiological condition and on type of maneuver with high values of likelihood. On the contrary, frequency values depend more on type of maneuver (likelihood around 98/99%) then psychophysiological condition.

Table 3. ANOVA results

Indicators	On psychophysiological condition			On type of maneuver	
	Baseline	Stopping maneuvers	Overtaking maneuvers	Sober Condition	Drunken Condition
Blinking	$F_{(1,37)} = 7.7$ $P < 0.01$	$F_{(1,37)} = 2.6$ $P = 0.12$	$F_{(1,37)} = 1.8$ $P = 0.2$	$F_{(2,56)} = 9.3$ $P < 0.01$	$F_{(2,56)} = 14.3$ $P < 0.01$
Frequency	$F_{(1,37)} = 0.03$ $P = 0.88$	$F_{(1,37)} = 0.13$ $P = 0.75$	$F_{(1,37)} = 0.25$ $P = 0.62$	$F_{(2,56)} = 5.1$ $P < 0.01$	$F_{(2,56)} = 4.8$ $P = 0.015$

4.2 Baseline Values

Analyses of blinking indicate a significant increase in blinking values (Fig. 4) under the effect of alcohol. From a numerical point of view, average values are 9% in sober condition and 13% in drunkenness. The average of values is a reliable indicator because of two reason: the standard deviation into two groups (3.6 in sobriety and 4.4 in drunkenness) and the trend for all couples of values that is never decreasing from sobriety to drunkenness.

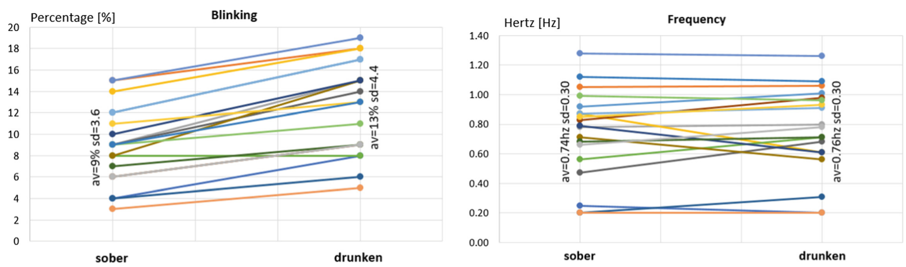

Fig. 4. Baseline values of blinking (left) and frequency (right)

It means that under the effect of alcohol the percentage of closed eyes frames is 4 percentage points more than sober condition. In terms of time or space, it represents a significant problem for road safety. In fact, in urban area (speed 50 km/h) considering 1 h the driver loses 2 km of the road due to alcohol drowsiness respect to sober condition; in extra-urban area (90 km/h), the same computation returns a value equal to 3.6 km.

Frequency values are almost constant between two groups in terms of average values, a little bit higher in the drunken sample: 0.74 Hz in sober condition and 0.76 Hz in drunkenness with standard deviation equal to 0.30 in both cases. If a value of blinking increases, keeping constant the rate, it means that the number of blinks is the same, but the driver takes more time to close and open eyes each times. For this reason, it is not possible to know how this difference (delta of 4%) is distributed for each blink, but it could be assume that it is divided in each blink homogeneously.

4.3 Stopping and Overtaking Measures

According to previous findings [13], in drunken condition during a stopping maneuver, the driver performs braking with high values of deceleration that lead to a high percentage of braking over the safety threshold of 8 m/s^2 (Fig. 5). In particular, this percentage in sobriety is around 25–30% of all braking performed and in drunkenness it exceeds 40%. It suggests, as mentioned by [20], a low risk perception of the potential risks of the road environment that lead drivers to brake with high value of deceleration and consequently with high value of brake pedal pressure.

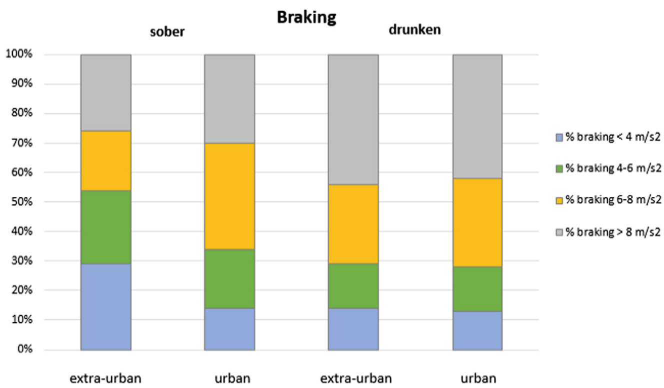

Fig. 5. Percentage of braking divided in classes [13]

In addition, the results of the overtaking maneuvers [13] confirm high risk under the alcohol effect levels in terms of number of performed overtaking in the ride: 31.8% more than in sober condition.

The eye-movements analysis, in this regard, show that in performing maneuvers, both stopping and overtaking, the driver's behaviour is more careful to the road environmental risks with a lower value of blinking and its rate.

As shown in Fig. 6 lower values of blinking respect to the baseline are recorded in both psychopsysiological conditions and in both maneuvers. It means that during a maneuver the percentage of closed eye frames is lower respect to baseline condition. This behaviour, with direct consequences on attention and concentration, careful and consciousness in performing a maneuver, is found in both psychopsysiological condition. From a numerical point of view, in stopping maneuver blinking is 5% in sober condition and 6% in drunkenness (respect each baseline there are 4 and 7 points of percentage of reduction). Instead, in overtaking maneuver blinking is 7% in sobriety and 8% in drunkenness (2 and 5 points of percentage of reduction).

The results of blinking, that are very reliable (both with a variance of psychophysiological condition and of type of maneuver) as ANOVA test established, show a greater reduction of blinking values respect to its baseline in drunkenness condition than in sobriety.

Furthermore, it is right to notice that the values of the percentage of blinking in drunkenness condition during a stopping or an overtaking maneuver is very close to the sober baseline (both less than the sober baseline, 9%). Therefore, the effect of a risky maneuver on drunken drivers' behaviour acts in terms of alert, lead the driver to pay attention to the road and restoring a blinking value similar to the baseline one (it must be specified that this result is referred to the BAC value analyzed in the present research, equal to 1).

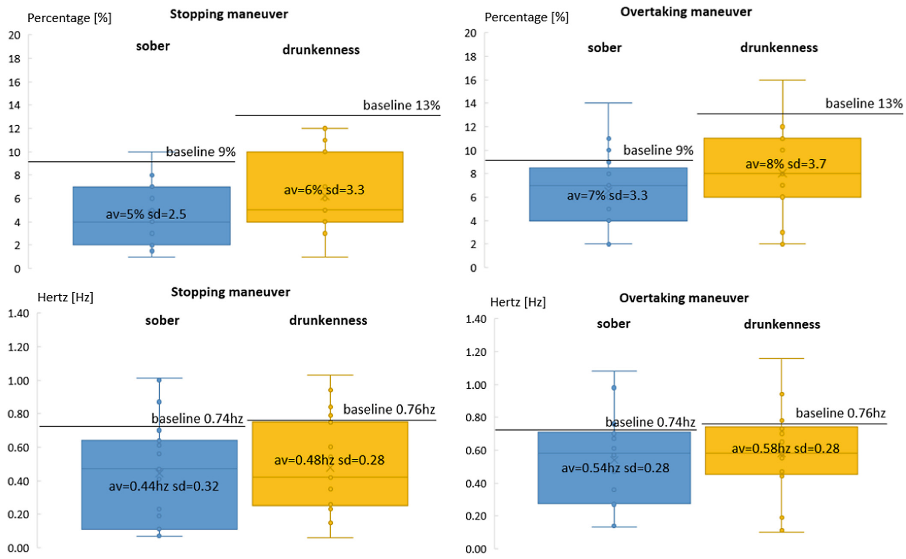

Fig. 6. Blinking and frequency in stopping and overtaking maneuver

The same behaviour of a reduction of values is found in terms of frequency. It could be due to a more attention to the road while the driver is performing the maneuver and a greater consciousness to the risk-taking. Lower value of blinking and its rate means lower closing time and a smaller number of blinks, on behalf of caution to the road risks. During a stopping maneuver there is a reduction of 0.30 and 0.28 Hz respectively in sober and drunkenness condition with a standard deviation around 0.30. In an overtaking maneuver the reduction is 0.20 Hz in sobriety and 0.18 Hz in drunkenness, with same standard deviation 0.28. As well in this case, the reduction is greater in stopping maneuver than in overtaking. Drivers pay more attention in stopping maneuver than in overtaking; it could be due to the environment where the maneuvers are performed, overtaking in extraurban are and stopping in urban area. This latter requires the ability to scan the road environment to predict the potential road risks.

Summarizing results point out two main findings: alcohol leads to a behaviour close to the drowsiness and tiredness, as shown by the drunken baseline values of blinking and its rate respect to sober condition. In performing a risky maneuver, there is an attitude to pay more attention to the road that result in lower value of blinking and frequency (lower time with closed eyes and lower number of blinks). This attitude is verified both in sober and in drunkenness condition, so that the values of blinking in drunken condition during a maneuver are close to sober blinking baseline.

5 Conclusion and Future Prospective

The present paper aims to investigate the driving behaviour under the effect of alcohol, by means of eye-movements. In particular, blinking measures during a virtual reality driving experiment are recorded thanks to an eye tracker camera and processed with an image analysis algorithm. The output measures are the blinking, expressed as the percentage of closed eyes referred to all the frames recorded during a simulation and its rate (frequency of blinks). This research is developed in the field of a project research aims to analyze the impact of alcohol on road safety to promote awareness campaigns “Drink or Drive”. In a previous research, developed by the authors [13], in the same virtual reality driving experiment the driving performances are recorded and analyzed to understand how much the alcohol affect the driving task ability.

Previous findings demonstrate that alcohol have a significant impact on reaction time and on the ability to risk-taking that lead drivers to do more risky maneuvers (as stopping and overtaking maneuvers). In this regard the present paper aims to answer to a research question: is it possible to correlate the eye measures with the driving performances measures to understand the alcohol-related accidents phenomenon?

The comparison between the blinking measures and the driving performances allow to understand more in deep the psychophysiological condition of the driver and how this latter affect the driving task. In this instance, the two kinds of measures support a wider knowledge of the “Drink and Drive” phenomenon in order to promote an awareness of the risk-taking under the effect of alcohol and to restrict the number of alcohol-related accidents.

Results show a reduction in attention and concentration after the alcohol assumption demonstrated by an increasing value of blinking in drunkenness condition respect to the sober one and a constant value of frequency. In performing risky maneuver, a reduction of blinking and its rate is observed compared to the baseline recorded for both sober and drunkenness. It could be imputed to a more attention to the road on behalf of a better scan to the potential road risk in both analyzed maneuver, more in stopping maneuver (higher delta values between blinking and its rate average and the corresponding baseline).

Considering a comparison with the driving performances results, the reduction in blinking values could be explain in terms of a lower risk perception of the driver maneuver performance in drunkenness (as high percentage of braking with value more than 8 m/s^2 and a higher number of overtaking show).

Concluding, it is important to emphasize on the innovation of the proposed approach in terms of integration between the blinking measures and the driving performances, both recorded in a virtual reality driving experiment, as driving risk perception assessment.

Hereafter, the authors will be involved in other studies in order to expand knowledge on the subject to promote and advance awareness campaigns. The project research could be extended by studying driving performance and eye-movements depending on different levels of BAC and integrating the analysis with another outcome measure (i.e. steering wheel, lane position, etc.).

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