Journal of Forensic and Legal Medicine 117 (2026) 103050

Contents lists available at ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/yjflm

Research Paper

Impact of psychoactive substances and attention-related impairments on driving performance: Sex differences and road crash involvement

Claudio Terranova [a,*], Clara Cestonaro [a], Stefano Palumbi [a], Laura Marino [a], Alessandro Gentili [a], Francesco Pozzebon [a], Rocco Miazzi [b], Anna Aprile [a]

[a] Legal Medicine and Toxicology, Department of Cardiac, Thoracic, Vascular Sciences and Public Health, University of Padova, via G. Falloppio n.50, Padova, 35121, Italy

[b] Sapienza University of Rome, Piazzale Aldo Moro 5, Rome, 00185, Italy

ARTICLE INFO

Keywords:
Attention disorders
Driving under the influence
Substance use disorder
Sex differences
Crash involvement

ABSTRACT

Introduction: Crashes are a global public health concern, with psychoactive substance use and attention impairments potentially increasing risk and affecting male and female drivers differently. This study aims to identify factors related to psychoactive substance use and attention impairments that predict road crash involvement by sex, offering insights for targeted prevention effort.

Methods: This observational study examined individuals assessed for driving license reissuance after driving under the influence of alcohol and/or drugs. Data collected included personal and sociodemographic details, results from a Continuous performance test (CPT-3) (a neuropsychological test assessing inattentiveness, impulsivity, sustained attention, and vigilance), and toxicological analyses of biological samples. Statistical analyses (chi-square, logistic regression, and ROC curve) aimed at identifing sex-specific predictors of road crash involvement.

Results: The study included 169 participants (82.8 % males, 17.2 % females). Initial univariate analyses indicated sex differences that were not confirmed after Bonferroni correction for multiple comparisons. Logistic regression found blood alcohol concentration predictive of crashes in males ($p = 0.005$, $OR = 2.52$), while inattentiveness was a major factor for females ($p = 0.045$, $OR = 12.0$). In the combined model, sex itself was not an independent predictor after adjusting for these factors. The model showed moderate accuracy for males (ROC-AUC = 0.695) and higher accuracy for females (ROC-AUC = 0.816), suggesting that inattentiveness may play a particularly important role in predicting crashes in the female subgroup.

Conclusions: Inattentiveness and alcohol use emerged as key predictors of crash involvement, with inattentiveness showing particular relevance in the female subgroup. Prevention should focus on modifiable risk factors rather than sex. The model's higher accuracy in females suggests attentional measures may help identify at-risk drivers, though the small female sample limits generalizability.

1. Introduction

Crashes are a widespread issue worldwide.[1] Those involved often face severe consequences, including death or serious injuries that can result in permanent or temporary disabilities.[2] For these reasons, crashes represent a significant socio-economic and public health concern.[3]

The weight of it is worsened by statistics; in fact, according to WHO, 1.19 million people die because of car crashes every year and 20 to 50 million suffer non-fatal injuries.[4]

Over the years, various risk factors have been identified; among these the use of psychoactive substances, mainly alcohol and cannabis,[5] accounts for a high percentage of the crashes.

About 32 % of all traffic crash fatalities in the United States involve drunk drivers[6]; in Europe the percentage is 25 %[7] and similar statistics are retrievable from many different single countries.[8–11]

The use of any psychoactive substance impairs driving ability

* Corresponding author.
E-mail addresses: claudio.terranova@unipd.it (C. Terranova), clara.cestonaro@phd.unipd.it (C. Cestonaro), stefano.palumbi@studenti.unipd.it (S. Palumbi), laura.marino@studenti.unipd.it (L. Marino), alessandro.gentili.1@studenti.unipd.it (A. Gentili), francesco.pozzebon@studenti.unipd.it (F. Pozzebon), rocco.miazzi@uniroma1.it (R. Miazzi), anna.aprile@unipd.it (A. Aprile).

https://doi.org/10.1016/j.jflm.2025.103050
Received 11 May 2025; Received in revised form 10 November 2025; Accepted 11 December 2025
Available online 12 December 2025
1752-928X/© 2025 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

altering cognitive functions[12]; moreover, the risk of car crashes increases with the dose and the type of substance used[13]; amphethamines and any combination of drugs, with or without alcohol, enhance this risk of at least 5 times.[14]

The neurobiological substrate underlying the link between substance use and the risk of crashes can be sought from the direct action of these molecules, both acute and chronic, on the brain, particularly on the basal ganglia, the amygdala and the prefrontal cortex.[15]

Notably, substance use is strongly associated with attention impairments, with evidence showing both direct cognitive deficits and attentional biases in individuals with substance use disorders. Multiple studies consistently report that individuals with substance use disorders (SUDs) exhibit significant impairments in attention and related cognitive domains, with robust evidence across age groups and substance types.[16–18] Cognitive impairment, including attention deficits, is considered a hallmark of SUDs and is linked to poorer treatment outcomes and higher relapse rates.[19–21] Attentional bias—where substance-related cues disproportionately capture attention—has also been identified as a key feature of SUDs, contributing to craving and relapse risk.[22]

Additionally, chronic substance use alters brain regions critical for attention, such as the prefrontal cortex and frontal lobes, leading to functional impairments.[19,23]

To investigate attention impairments, the Conners' Continuous Performance Test – Third Edition (CPT-3) is a valuable tool to explore alterations in attentional dimensions.[24] Continuous performance tests have also been widely employed in the study of attention-deficit/hyperactivity disorder (ADHD), a persistent neurodevelopmental condition frequently comorbid with substance use disorders (SUDs) and associated with increased crash risk.[24–27]

For these reasons, and given the comorbidity between SUD and attention impairments, it is important to further investigate individuals involved in car crashes who were driving under the influence of psychoactive substances. This can help identify potential impairments in attention within this group, which is essential for developing targeted prevention, therapy, and rehabilitation strategies. Additionally, due to significant sex differences in substance use patterns and road crash involvement,[28] it is crucial to analyze males and females separately to ensure that the findings guide tailored interventions.

Given the above, the aim of this study is to identify and analyze factors related to psychoactive substance use and attention impairments (as assessed by CPT-3) that may predict road crash involvement in both males and females. By understanding the specific predictors that increase the risk of crashes for each sex, the study aims to propose targeted interventions and strategies to effectively reduce their occurrence.

2. Methods

2.1. Population studied

This observational study examines a population of individuals who were found driving under the influence (DUI) of psychoactive substances, including alcohol and other drugs, as defined by Italian legislation. Participants, aged between 18 and 65 years, were recruited from the Complex Unit of Legal Medicine and Toxicology at the University Hospital of Padua during mandatory procedures for driver's license reinstatement following a DUI episode. DUI was determined by a blood alcohol concentration above 0.5 g/L or a positive test for illicit substances. Refusal of alcohol/drug determination is another reason for the driver to be examined in an institution with expertise in alcohol drug use for driving license reinstatement.

Inclusion criteria required participants to provide written informed consent for the study. Exclusion criteria included refusal to participate, a diagnosis of substance use disorder (SUD), psychiatric or neurological disorders, visual impairment, sleep disorders, or ongoing psychopharmacological treatment, as these factors could confound attention-related assessments. Refusal to participate was not statistically documented.

The study protocol (code 5543/AO/22, ID study 21052) was approved by the Ethics Committee for Clinical Experimentation of the Province of Padua on September 8, 2022.

2.2. Methodological assessment protocol

The methodological assessment protocol followed the same approach used in a previous study by the authors[29] and included: 1) obtaining informed consent, 2) collecting personal and sociodemographic data, 3) administering the CPT-3 test, and 4) gathering biological samples for toxicological analysis.

Personal and sociodemographic data, along with DUI-related information, were obtained through medical history interviews or official documents. Examinations were conducted by physicians who were either specialized or in training in Legal Medicine at the University Hospital of Padua. All data were entered into a database using alphanumeric codes for identification. The collected data included both continuous and ordinal variables, such as date of birth, biological sex, driver's license type, family history of alcohol or substance use disorders, education, marital status, occupation, and smoking habits. Some variables were dichotomous, with the presence of a condition coded as 1 and its absence as 0, while others represented different forms or categories. Additional data collected included the date of the DUI incident, recidivism, type of DUI (alcohol and/or drugs), blood alcohol levels, substances involved, and any related crashes, as documented in police reports.

Biological samples (hair and urine) were collected for toxicological analysis to objectively assess substance use, focusing on illicit psychoactive substances and alcohol use. Hair EtG levels above 30 pg/mg[30] were used to determine unfitness to drive, as was the presence of illicit substances exceeding the cut-off values established by the Society of Hair Testing.[31] Excessive alcohol or substance use impacted fitness assessments but was not automatically indicative of a substance use disorder (SUD) diagnosis.

Data from the Continuous Performance Test–Third Edition (CPT-3)[32] were also collected. This neuropsychological test assesses various aspects of attention, including inattentiveness, impulsivity, sustained attention, and vigilance.

2.3. CPT-3 test

The Conners' Continuous Performance Test (CPT-3) is one of the most widely used assessments for measuring sustained attention. The test is administered via computer, where participants must quickly press a button whenever a letter appears on the screen, except when the letter "X" is displayed. During the 14-min test, the software records several metrics: "C-style" refers to the style of responding; "detectability" measures the ability to discriminate targets (letters other than X) from non-targets (X); "omissions" indicates the rate of missed targets; "commissions" represents the rate of incorrect responses (100 msec or more) to non-targets; "perseverations" denotes the rate of anticipatory, repetitive, or random responses (under 100 msec); "hit reaction time" (HRT) is the average response speed; "hit reaction time standard deviation" (HRT-SD) assesses response speed consistency; "variability" reflects fluctuations in response speed consistency; "hit reaction time block change" captures changes in HRT across blocks; and "hit reaction time interstimulus interval (ISI) change" measures changes in HRT across ISIs. These metrics are used to evaluate four key attention dimensions: inattention, impulsivity, sustained attention, and vigilance.[29] The software then provides a likelihood score for ADHD ranging from very high to minimal or no indication.

- Inattentiveness is suggested by poor Detectability, high percentage of Omissions and Commissions, a slow HRT and high level of inconsistency in response speed (HRT SD and Variability).
- Impulsivity is characterized by faster than normal HRT and a higher than average rate of Commissions and/or Perseverations.
- Sustained attention evaluates the ability to maintain consistent performance throughout the test (changes in HRT block change T-score, patterns of Omissions and Commissions by Block raw scores).
- Vigilance assesses the capacity to sustain performance over time.

At the end of the assessment, each dimension is rated to indicate whether there is no indication, some indication, or a strong indication of attention-related issues.

2.4. Statistical analysis

The analysis was conducted in several stages to explore and model the relationship between predictor variables and road crash involvement, separately for males and females.

First, personal, sociodemographic, and clinical data, as well as CPT-3 test results obtained at the end of the recruitment phase, were anonymously entered into an Excel spreadsheet. A descriptive analysis was then performed, with summary statistics calculated for all variables, stratified by sex. This included means and standard deviations for continuous variables and frequencies for categorical variables.

Any differences between males and females were evaluated using the Bonferroni correction to account for multiple comparisons, providing a more conservative interpretation of statistical significance.

To analyze the association between previous road crash involvement and the predictor variables for both males and females, chi-square tests were used for dichotomous variables, while t-tests and Mann–Whitney U tests were applied to parametric and non-parametric continuous variables, respectively, with the significance level set at $p < 0.05$. These same analyses were also conducted for the CPT-3 subscales.

Variables that showed significant differences ($p < 0.05$) between the two groups (road crash involvement vs. no road crash involvement) in the preliminary analysis were subsequently included in a stepwise multivariate binary logistic regression model, conducted separately for males and females. The stepwise approach was selected because the initial set of predictors was relatively large compared to the number of events, and several variables were expected to be correlated.

This method allows for the sequential inclusion and exclusion of variables based on their statistical contribution to the model, resulting in a final parsimonious model that minimizes the risk of overfitting while retaining only those predictors with the strongest association with the outcome. This strategy is particularly appropriate for exploratory studies where the goal is to identify potential risk factors for future investigation, rather than to build a definitive predictive model.

In addition to the sex-stratified stepwise models, a combined logistic regression analysis was performed including all participants and entering sex as an independent variable, along with all variables that were significant in the univariate analyses. This analysis was carried out to assess whether sex independently influenced road crash involvement after adjusting for other relevant factors.

As the primary aim of this study was to evaluate the model's ability to classify individuals as involved or not involved in a road crash, the Receiver Operating Characteristic (ROC) analysis was used to assess its discriminative performance. This approach provides a comprehensive evaluation of sensitivity and specificity across all possible classification thresholds, offering a robust measure of the model's accuracy and practical applicability.

To evaluate model performance, the Area Under the Receiver Operating Characteristic (ROC-AUC) curve was calculated for each model. In addition to AUC, further evaluation metrics included accuracy, precision, recall (the proportion of actual positive cases correctly identified, also called sensitivity), and F1-score (a single measure that combines precision and recall to show how well the model balances identifying true positives while avoiding false positives) to provide a comprehensive assessment of each model's classification ability.

The Gini coefficient (a value derived from AUC that reflects the model's overall ability to distinguish between individuals involved in crashes and those not involved) was computed from the AUC to gauge overall discriminative performance, while Youden's Index (J Statistic) was used to determine the optimal balance between sensitivity and specificity for classifying those involved in crashes versus those not involved. The optimal cutoff point for classification was determined based on the Youden's Index to enhance the predictive accuracy of the models.

All analyses were performed using IBM SPSS Statistics for Windows, version 28.0.[33]

3. Results

3.1. Personal data, socioeconomic factors, DUI variables, and CPT-3 results

The study included 169 subjects (140 males [82.8 %] and 29 females [17.2 %]). Personal data and socioeconomic factors, both overall and by

Table 1
Personal data and socio-economic factors, in males and females.

Variable	Total $n = 169$ (100 %)	Males $n = 140$ (100 %)	Females $n = 29$ (100 %)	P-value*
PERSONAL DATA				
Age at examination, years, mean (Standard deviation)	37.74 (11.71)	38.51 (11.90)	34.03 (10.13)	0.061
Family history of substance use disorder	10 (5.9)	8 (5.7)	2 (6.9)	0.538
Negative family hystory of substance use disorder	159 (94.1)	132 (94.3)	27 (93.1)	
Tobacco use**				
No use	55 (32.7)	49 (35.3)	6 (20.7)	0.037
Less than 20 cigarettes per day	100 (59.1)	77 (55.4)	23 (79.3)	
More than 20 cigarettes per day	13 (7.7)	13 (9.4)	0 (0.0)	
SOCIO-ECONOMIC FACTORS				
Education**				
8 years	33 (19.6)	31 (22.3)	2 (6.9)	0.045
13 years–high school degree	109 (64.9)	90 (64.7)	19 (65.5)	
Bachelor's degree	26 (15.5)	18 (12.9)	8 (27.6)	
Employment Situation**				
Dependent	116 (69.0)	98 (70.5)	18 (62.1)	0.083
Freelance	32 (19.0)	28 (20.1)	4 (13.8)	
Unemployed	18 (6.5)	5 (5.8)	2 (10.3)	
Student	7 (4.2)	4 (2.9)	3 (10.3)	
Retired	2 (1.2)	1 (0.7)	1 (3.4)	
Marital status**				
Single	99 (58.9)	82 (59)	17 (58.6)	0.146
Married	55 (32.7)	47 (33.8)	8 (27.6)	
Divorced	13 (7.7)	10 (7.2)	3 (10.3)	
Widow	1 (0.6)	0 (0.5)	1 (3.4)	

Note. * *P*-values refer to chi-square test for dichotomous variables and to Mann-Whitney test for continuous data with non-parametric distribution; The Bonferroni correction was applied to account for multiple comparisons. After adjustment ($p < 0.008$), no variables remained statistically significant; ** Data may be incomplete for some subjects. The sum of the numbers and the percentages with reference to the variable considered may not correspond to the total or to 100 %.

sex, are presented in Table 1. DUI variables, toxicological analyses, and judgments of fitness or unfitness to drive, both overall and by sex, are detailed in Table 2. CPT-3 results concerning the attention dimension are reported in Tables 3 and 4.

Differences between the two groups were initially observed for tobacco use ($p < 0.037$) and education level ($p < 0.045$), while no differences emerged for age, family history of substance use disorder, employment status, and marital status. However, after applying the Bonferroni correction to adjust for multiple comparisons, none of these differences remained statistically significant.

Most subjects in the study were found to be driving under the influence of alcohol (77.4 %). Additionally, 39 % of the subjects had a blood alcohol concentration exceeding 1.5 g/L at the time of the DUI. Furthermore, 27.8 % of the sample were involved in a road crash. Notably, 16 subjects were found to have driven under the influence on two or more occasions. Following medicolegal toxicological assessment, 24.6 % of the cases resulted in a judgment of being unfit to drive (11.4 % due to excessive alcohol consumption, 1.2 % due to excessive alcohol consumption associated with illicit substance use, and 12 % due to illicit substance use).

The distribution of these parameters differed between males and females only in relation to recidivism; notably, according to the official records, none of the female subjects had a history of multiple DUI episodes.

Regarding the CPT-3 parameters, differences between males and females were observed in 'perseveration' (repeated incorrect responses), 'HRT-ISI change' (variability in reaction time), and Vigilance (ability to

Table 2
DUI variables and judgement of fitness/unfitness to drive in males and females.

Variable	Total $n = 169$ (100 %)	Males $n = 140$ (100 %)	Females $n = 29$ (100 %)	P-value*
DRIVING UNDER THE INFLUENCE VARIABLE				
Age at DUI, years, mean (Standard deviation)	33.87 (11.54)	34.39 (11.86)	31.38 (9.66)	0.290
Type of DUI**				
DUI – Alcohol only	127 (77.4)	105 (77.2)	22 (78.6)	0.975
DUI - Psychoactive substances other than alcohol	24 (14.6)	20 (14.7)	4 (14.3)	
DUI - Alcohol plus psychoactive substances	12 (7.3)	10 (7.4)	2 (7.1)	
BAC at DUI**	1.41 (0.67)	1.40 (0.69)	1.49 (0.55)	0.266
BAC at DUI**				
0.5–0.8 g/L	29 (19.5)	25 (20.3)	4 (15.4)	0.505
0.8–1.5 g/L	55 (36.9)	46 (37.4)	9 (34.6)	
1.5–2.5 g/L	50 (33.6)	39 (31.7)	11 (42.3)	
>2.5 g/L	8 (5.4)	8 (6.5)	0 (0)	
Refusal of alcohol determination	5 (2.99)	5 (2.99)	5 (2.99)	
Road crash at DUI**	47 (27.8)	36 (25.7)	11 (37.9)	0.135
No road crash	122 (72.2)	104 (74.3)	18 (62.1)	
DUI recidivism**	16 (9.5)	16 (11.4)	0 (0)	0.042
First DUI episode	124 (90.5)	124 (88.6)	29 (100)	
Toxicological analysis**				
EtG values < 5 pg/mg	57 (44.9)	45 (42.5)	12 (57.1)	0.395
EtG values 6–29 pg/mg	48 (37.8)	41 (38.7)	7 (33.3)	
EtG values ≥ 30 pg/mg	22 (17.37)	20 (18.9)	2 (9.5)	
FITNESS OR UNFITNESS TO DRIVE				
Fit to drive	126 (75.4)	104 (75.4)	22 (75.9)	0.237
Unfitness - excessive alcohol consumption	19 (11.4)	18 (13.0)	1 (3.4)	
Unfitness - Illicit substance use	20 (12)	15 (10.9)	5 (17.2)	
Unfitness - excessive alcohol consumption and illicit substance use	2 (1.2)	1 (0.7)	1 (3.4)	

Note: BAC = Blood alcohol concentration; DUI = driving under the influence; EtG = ethyl glucuronide.
* *P*-values refer to chi-square test for dichotomous variables and to Mann-Whitney test for continuous data with non-parametric distribution; The Bonferroni correction was applied to account for multiple comparisons. After adjustment ($p < 0.006$), no variables remained statistically significant; ** Data may be incomplete for some subjects. The sum of the numbers and of the percentages with reference to the variable considered may not correspond to the total or to 100 %.

Table 3
Parameters measured by the CPT-3[32], in males and females.

Variable	Males value (mean)	Females value (mean)	P-value*
C-style	52.19 (14.42)	55.24 (14.19)	0.301
Detectability	55.46 (10.40)	55.48 (10.71)	0.990
Omissions	57.04 (15.54)	59.93 (16.29)	0.399
Commissions	53.25 (10.62)	51.76 (10.87)	0.443
Perseverations	48.11 (6.58)	50.28 (8.88)	**<0.001**
HRT (hit reaction time)	48.66 (7.98)	48.48 (10.48)	0.745
HRT SD (HRT standard deviation)	48.25 (7.06)	49.07 (9.29)	0.924
Variability	48.54 (7.96)	48.86 (6.96)	0.488
HRT block change	49.35 (10.66)	50.14 (9.02)	0.512
HRT ISI change	47.19 (7.04)	50.66 (7.14)	0.031

Note. * *P*-values refer to T-test for continuous data with parametric distribution, and to Mann-Whitney test for continuous data with non-parametric distribution. ** The Bonferroni correction was applied to account for multiple comparisons. The adjusted significance threshold for this table was $p < 0.005$. Only variables with p-values below this threshold were considered statistically significant (shown in bold).

Table 4
Attention dimension in males and females.

Variable	Males 140 (100 %)	Females 29 (100 %)	P-value*
Probability ADHD**			
0	76 (54.3)	14 (48.3)	0.447
2	51 (36.4)	12 (41.4)	
3	10 (7.1)	1 (3.4	
4	3 (2.1)	2 (6.9)	
Inattentiveness***			
1	65 (46.4)	12 (41.4)	0.840
2	41 (29.3)	10 (34.5)	
3	34 (24.3)	7 (24.1)	
Impulsivity***			
1	117 (83.6)	21 (72.4)	0.366
2	11 (7.9)	4 (13.8)	
3	12 (8.6)	4 (13.8)	
Sustained attention***			
1	89 (63.6)	20 (69)	0.166
2	46 (32.9)	6 (20.7)	
3	5 (3.6)	3 (10.3)	
Vigilance***			
1	110 (78.6)	21 (72.4)	0.036
2	28 (20)	5 (17.2)	
3	2 (1.4)	3 (10.3)	

Note. * *P*-values refer to chi-square test. The Bonferroni correction was applied to account for multiple comparisons. After adjustment ($p < 0.01$), no variables remained statistically significant; ** The probability of ADHD as determined by the CPT-3 was categorized into levels: very high, high, moderate, minimal, or absent, and these were coded as 0, 1, 2, 3, and 4, respectively.*** The three levels of another dimension (absent, minimal, and strong indication) were coded as 1, 2, and 3, respectively.

maintain attention over time) with vigilance showing a p-value of 0.036. After applying the Bonferroni correction for multiple comparisons, only perseveration remained statistically significant.

3.2. Parameters related to road crash involvement in males and females

The study aimed to identify factors associated with road crash involvement, analyzed separately for males and females. Initially, a univariate analysis was performed to explore the relationship between individual variables and road crash involvement. This was followed by a binary logistic regression analysis, with road crash involvement as the dependent variable, to identify significant predictors while simultaneously accounting for multiple factors within each sex group.

Table 5 presents the variables that significantly differed between male subjects involved in a road crash and those not involved. P-values for variables that showed no significant differences between the two groups, including toxicological analysis of hair and urine (hair and urine toxicology results were collected to objectively assess substance use) are provided in the supplementary materials (Table 5 – Supplementary). The variables included in the logistic regression model were: age at examination (p = 0.018), age at DUI (p = 0.016), blood alcohol concentration (BAC) at DUI (p = 0.020), history of substance use disorder (p = 0.027), and recidivism (p = 0.046). Among these, BAC (Table 6) was identified as a significant risk factor for previous road crash involvement (p = 0.005, OR = 2.52, 95 % CI [1.32–4.81]). The detailed results of the stepwise logistic regression analyses for males, including all variables entered and their respective parameters, are provided in the supplementary material (Supplementary Table 6).

Table 7 presents the variables that significantly differed between female subjects involved in a road crash and those not involved. P-values for variables that did not show significant differences between the two groups, including toxicological analysis of hair and urine, are provided in the supplementary materials (Table 7 – Supplementary). Detectability (p = 0.035), HRT-SD (p = 0.022), inattentiveness (p = 0.006), and sustained attention (p = 0.035) were found to differ between the two groups in the univariate analysis. However, since detectability and HRT-SD are related to and influence inattentiveness according to the CPT-3 software, they were excluded from the regression model to avoid redundancy. Inattentiveness (Table 8) was ultimately identified as a significant risk factor for previous road crash involvement (p = 0.045, OR = 12.0, 95 % CI [1.053–136.794]). The detailed results of the stepwise logistic regression analyses for females, including all variables entered and their respective parameters, are provided in the supplementary material (Supplementary Table 8).

In addition to the sex-stratified stepwise models, a univariate analysis was performed including all participants and comparing drivers involved in road crashes versus those not involved. The following variables showed significant differences between the two groups: family history of substance use disorder (p = 0.019), DUI recidivism (p = 0.043), toxicological analysis (p = 0.014), inattentiveness (p = 0.030), age at DUI (p = 0.050), and BAC (p = 0.009).

Although sex was not significantly different between the two groups (p = 0.135), it was nevertheless included as an independent variable in a combined logistic regression analysis, together with all variables that were significant in the univariate analyses.

In this multivariate model, inattentiveness (Table 9) and BAC were ultimately identified as significant risk factors for previous road crash involvement (inattentiveness: p = 0.007, OR = 5.34, 95 % CI [1.566–18.219]; BAC: p = 0.008, OR = 2.79, 95 % CI [1.305–5.970]).

Conversely, an EtG concentration consistent with social alcohol use emerged as a protective factor (p = 0.001, OR = 0.119, 95 % CI [0.033–0.437]).

The detailed results of the logistic regression analysis for the entire sample, including all variables entered and their respective parameters, are provided in the supplementary material (Supplementary Table 9).

Table 5
Univariate analysis – Road crash involvement in males.

Variable	Road accident *n* = 36 (100 %)	No road accident *n* = 104 (100 %)	P-value*
VARIABLE			
Age at examination, years, mean (Standard deviation)	42.61 (11.49)	37.09 (11.76)	0.018
Age at DUI, years, mean (Standard deviation)	38.22 (12.01)	33.06 (11.57)	0.016
BAC at DUI**	1.69 (0.85)	1.30 (0.60)	0.020
History of substsance use disoder**	5 (62.5)	3 (37.5)	0.027
Negative hystory of substance use disoder	31 (23.5)	101 (76.5)	
DUI recidivism**	1 (2.8)	15 (14.4)	0.046
First DUI episode	35 (97.2)	89 (85.6)	

Note. * *P*-values refer the chi-square test was used for dichotomous variables, the *t*-test for continuous variables with a parametric distribution, and the Mann–Whitney *U* test for continuous variables with a non-parametric distribution.
Note: BAC = Blood alcohol concentration; DUI = driving under the influence; ** Data may be incomplete for some subjects. The sum of the numbers and of the percentages with reference to the variable considered may not correspond to the total or to 100 %.

Table 6
P-Value, Odds ratio and Confidence interval of the variables associated to road crash involvement in males using multiple logistic regression model.

Variable	P-value	OR*	95 % CI**
BAC	0.005	2.52	1.32–4.18

Variables in the model: Age at examination, age at DUI, BAC at DUI, Hystory of substance use disoder, Recidivism.
Note. *OR=Odds ratio; ** CI= Confidence interval; BAC = Blood alcohol concentration.

Table 7
Univariate analysis – Road crash involvement in females.

Variable		Road accident *n* = 11 (100 %)	No road accident *n* = 18 (100 %)	P-value*
VARIABLE				
Detectability (SD)**		42.61 (11.49)	37.09 (11.76)	0.035
HRT-SD (SD)**		38.22 (12.01)	33.06 (11.57)	0.022
Inattentiveness	1	4 (36.4)	8 (44.4)	0.006
	2	1 (9.1)	9 (50)	
	3	6 (54.5)	1 (5.6)	
Sustained attention	1	5 (45.5)	15 (83.3)	0.035
	2	5(45.5)	1 (5.6)	
	3	1 (9.1)	2 (11.1)	

Note: * *P*-values refer to chi-square test for ordinal variables and to Mann-Whitney test for continuous data with non-parametric distribution. ** SD refers to standard deviation.

Table 8
P-Value, Odds ratio and Confidence interval of the variables associated to road crash involvement in females using multiple logistic regression model.

VARIABLE	P-value	OR*	95 % CI**
Inattentivenss***	0.027		
Inattentiveness 1	0.217	0.222	0.020–2.424
Inattentivenss 2	**0.045**	12.000	1.053–136.794

Variables in the model: Inattentiveness, sustained attention.
Note. *OR=Odds ratio; ** CI= Confidence interval; *** Reference category: no indication of inattentiveness.

Table 9
P-Value, Odds ratio and Confidence interval of the variables associated to road accident involvement in the whole sample using multiple logistic regression model.

VARIABLE	P-value	OR*	95 % CI**
DUI recividism	0.068	0.124	0.013–1.166
EtG values <5 pg/mg	0.006		
EtG values ≥30 pg/mg	0.320	0.505	0.131–1.1941
EtG values 6–29 pg/mg	**0.001**	0.119	0.033–0.437
BAC	**0.008**	2.79	1.30–5.97
Inattentivenss* **	0.024		
Inattentiveness 1	0.107	2.753	0.803–9.437
Inattentivenss 2	**0.007**	5.342	1.566–18.219

Variables in the model: Sex, DUI recidivism, Family history of substance use disorder, Toxicological analysis (Etg values), BAC, Inattentiveness.
Note. *OR=Odds ratio; ** CI= Confidence interval; *** Reference category: no indication of inattentiveness.

3.3. Prediction road crash involvement among males and females

The logistic regression models were developed to predict road crash involvement among males and females separately. The models were then evaluated based on the area under the receiver operating characteristic (ROC-AUC) curve. Below are the detailed results for each sex.

The results for the male group indicated that the logistic regression model demonstrated a moderate ability to discriminate between those who were involved in a road crash and those who were not. The area under the ROC curve (ROC-AUC) for the male model was 0.695 (Fig. 1), with a standard error of 0.053. The AUC was statistically significant ($p = 0.000252$), and the 95 % confidence interval ranged from 0.591 to 0.800, suggesting some variability in the model's performance. Additionally, the model achieved an accuracy of 75.42 %, a precision of 58.33 %, a recall of 22.58 %, and an F1-score of 32.56 %, reflecting a balanced performance in correctly predicting road crash involvement.

Further evaluation metrics for the male model included a Gini coefficient of 0.391, which reflects a moderate discriminative ability. The Youden's Index was 0.328, indicating the optimal balance between sensitivity and specificity for distinguishing between the two groups. The optimal cutoff value was identified at 0.222.

For the female group, the logistic regression model showed a better performance in discriminating between those who were involved in a road crash and those who were not. The ROC-AUC for the female model was 0.816 (Fig. 2), with a standard error of 0.085. This AUC was also statistically significant ($p = 0.000197$), with a 95 % confidence interval ranging from 0.649 to 0.982, indicating a high level of accuracy in the model's predictions. Additionally, the model achieved an accuracy of 79.31 %, a precision of 85.71 %, a recall of 54.55 %, and an F1-score of 66.67 %, reflecting a balanced performance in correctly predicting road crash involvement.

Additional evaluation metrics for the female model showed a Gini coefficient of 0.631, signifying a good discriminatory power. The Youden's Index for the female model was 0.489, indicating the best balance between sensitivity and specificity for distinguishing between those involved in crashes versus those not involved. The optimal cutoff value was determined at 0.595.

4. Discussion

Attention deficit disorders and the use of psychoactive substances are well-established risk factors for crashes.[13,34] These conditions can impair cognitive and executive functions such as attention, inhibition, working memory, reaction time, and impulse control, increasing the likelihood of risky driving behaviors.[35] Our study's comprehensive approach—comparing male and female drivers using circumstantial, clinical, medico-legal, toxicological-forensic, and neuropsychol ogical-forensic data—introduces a novel perspective. Additional variables not previously examined by the same authors[1,29,36] were included in the study, allowing for a more nuanced understanding of factors influencing fitness to drive. The decision to include female subjects is crucial, as existing literature often focuses predominantly on males, despite well-documented sex differences in psychoactive substance use[37] and road crash involvement.[38]

Given that this is an exploratory study with a relatively limited

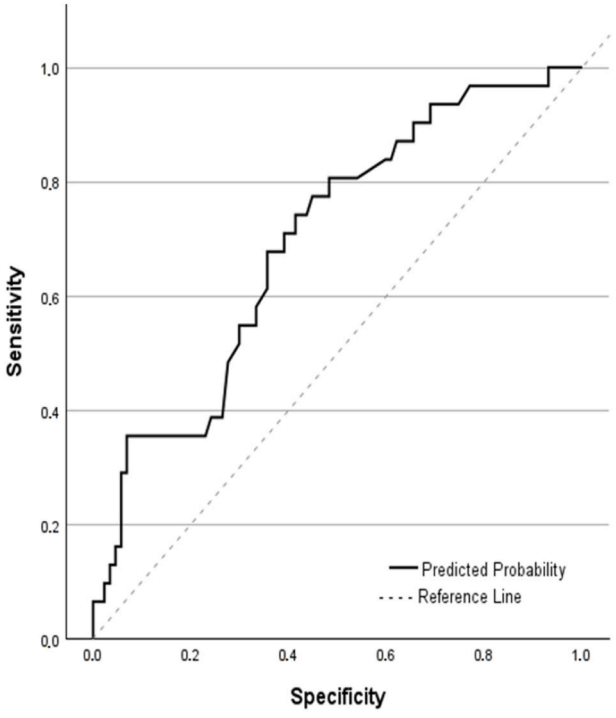

Fig. 1. ROC Curve for the Logistic Regression Model predicting road crash involvement among males.

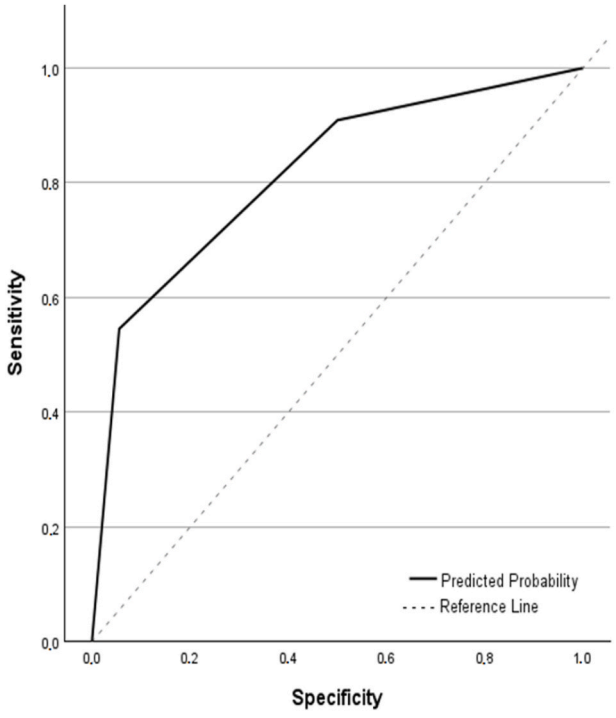

Fig. 2. ROC Curve for the Logistic Regression Model predicting road crash involvement among females.

sample size, we initially examined sex-related differences using unadjusted p-values to identify potential trends. However, after applying the Bonferroni correction for multiple comparisons, only the variable "perseverations" remained statistically significant, while the other associations lost statistical significance. Therefore, the other findings discussed below should be interpreted with caution and considered hypothesis-generating rather than definitive conclusions.

Our results based on raw p-values suggested differences between male and female drivers in terms of educational level, tobacco consumption, recidivism in traffic code violations, and alterations in specific attention parameters. Although these differences were not confirmed after the Bonferroni correction, they may still offer exploratory insights that could be considered in future assessments and rehabilitation programs for drivers seeking license reinstatement.

In our sample, women were more likely to hold a bachelor's degree compared to men. This observation, while failing to reach statistical significance after adjustment, might reflect specific characteristics of the cases handled by our institution rather than a broader trend. This pattern, consistent with our previous study[29] contrasts with the general literature, which often associates lower educational attainment with deviant behavior and riskier driving patterns.[39] Notably, most studies in this field focus predominantly on male drivers, potentially overlooking sex-specific factors that could influence educational outcomes and driving behaviors.

Similarly, the tendency for men to smoke heavily (more than 20 cigarettes per day), although not retained after correction, is consistent with both national[40] and international epidemiological data,[41] which demonstrate a higher prevalence of substance use disorders, including tobacco use, among men. Notably, our sample shows a higher prevalence of tobacco use compared to the general population.[42] This finding likely reflects the well-documented co-occurrence of alcohol and tobacco use.[43]

Although not statistically confirmed after correction, the trend toward higher tobacco use among males may still be relevant from a clinical perspective, as heavy smoking has been linked to increased risk-taking behaviors and impaired cognitive functions, such as attention and decision-making—factors that are crucial for safe driving.[44] Additionally, it is possible that heavy tobacco use in men correlates with other co-occurring disorders, such as alcohol use, which may further impair driving abilities.[43]

The observed trend toward a higher rate of recidivist offenders among male drivers, although not confirmed statistically after correction, is consistent with previous studies reporting a greater prevalence of this behavior in males.[12,42] DUI recidivism is a complex phenomenon influenced by multiple factors, which may contribute to its higher occurrence among males.[45]

In terms of attention metrics, the only parameter that remained significant after Bonferroni correction was "perseverations". This result highlights a potential sex-related difference in response on the CPT-3 test that warrants further investigations. Differences observed in vigilance and other attention measures did not remain significant after correction and should be interpreted as exploratory trends. Although caution is needed when interpreting this finding due to possible confounding factors (e.g., selection bias, type of test, etc.) and the low sample size, the result seems consistent with literature data identifying attention problems more than impulsivity or hyperactivity in females.[46,47] This difference could also reflect the influence of various combined factors, including neurobiological, psychological, and sociocultural elements not considered in this study[48,49] and potentially affecting female subjects found driving under the influence of psychoactive substances.

Regarding the risk factors for crashes, it is interesting to observe the differences between the two populations (males and females). In men, blood alcohol concentration (BAC) at the time of the crash was found to correlate with, and increase, the risk of belonging to the group involved in crashes. This finding is not surprising, as numerous studies have demonstrated a direct correlation between blood alcohol concentration and impaired driving ability, with an increased risk of being involved in a crash as blood alcohol levels rise.[50–52] It should be noted that individuals with a diagnosed substance use disorder were excluded from the study. This criterion, while potentially reducing the upper range of BAC values in the sample, was intentionally applied to minimize confounding effects related to chronic substance use and to better characterize the relationship between acute alcohol intake and crash risk in non-dependent drivers. Indeed, chronic alcohol use disorder may influence crash risk not only through acute intoxication but also via long-term neurocognitive and behavioral alterations – such as impaired executive functions, increasing impulsivity – that can affect driving performance even at low BAC levels. Therefore, the exclusion of participants with alcohol use disorder aimed to reduce heterogeneity and help isolate the acute, dose-dependent effects of alcohol among non-dependent drivers. However, the predictive model based on logistic regression yielded only partially satisfactory results. The findings of the predictive model highlight the complexity of crash involvement and suggest the influence of additional factors not analyzed in our study. Variables such as impulsivity, personality traits,[53] and environmental influences[54] —difficult to quantify and outside the scope of this analysis—may significantly impact driving behavior and crash risk. Furthermore, unexamined factors like alcohol consumption patterns,[55] lifestyle choices, and other psychosocial variables could also contribute to the risk of road crashes.

The analysis of female subjects involved in crashes revealed a notable association between poorer performance on certain CPT-3 parameters and their history of road crashes. Specifically, 'inattentiveness' emerged as a significant risk factor, suggesting that attentional deficits may play an important role in crash risk among these drivers. However caution is required when interpreting these data due to the limited number of female participants and the exploratory nature of the analysis, which may increase the risk of overfitting. Nonetheless, this result could indicate attention impairment in our sample of female drivers involved in crashes, aligning with previous research.[56] Studies suggest that inattention contributes more significantly to severe crashes than to less severe ones, with the relationship varying depending on the type of inattention involved.[56] The logistic regression model developed for the female group of our study showed a robust ability to distinguish between those involved in crashes and those who were not, as evidenced by a ROC-AUC.

The fact that toxicological variables did not appear to play a role in our sample of female subjects, as they did in male subjects, does not rule out the possibility of an additive or multiplicative effect of psychoactive substance use on attention impairment. These findings highlight the importance of considering sex-specific patterns in substance use and their potential impact on cognitive functions. Female drivers might consume substances differently or experience subtler effects that interact with existing attentional deficits, warranting further investigation.

When considering the entire sample in a combined logistic regression model, inattentiveness and BAC emerged as independent risk factors for road crash involvement, while an EtG concentration consistent with social alcohol use appeared as a protective factor.

Although inattentiveness was more prevalent among females in our sample, sex itself was not independently associated with crash risk, indicating that the observed gender differences are driven by these underlying variables rather than by sex alone.

These findings highlight the importance of focusing on modifiable risk factors, such as alcohol use and attentional control, when assessing fitness to drive. In our study, inattentiveness was more prominent in the female subgroup, but this result should be interpreted cautiously due to the small number of female participants and the exploratory nature of the analysis.

Future research with larger and more balanced samples is needed to confirm whether this pattern is reproducible and to guide the

development of targeted preventive strategies. Such strategies might include cognitive and attentional training, behavioral programs promoting safe driving, structured monitoring, and temporary restrictions on high-risk driving situations. At this stage, these proposals are conceptual and should not be considered formal recommendations until validated by further studies.

5. Limitations and future perspectives of the study

The primary limitation of this study is the low representation of female subjects, which necessitates extending the recruitment phase to increase their representativeness. In particular, the limited number of female participants (n = 29) strongly affects the statistical power to detect true sex differences and does not allow reliable characterization of the population of female impaired drivers. Consequently, findings pertaining to females should be considered preliminary and exploratory. This disparity between male and female sample sizes, reflecting the actual referral patterns to our clinic, presents a substantial constraint on the study's capacity to fully achieve its objective of examining sex-specific differences in the relationship among psychoactive substance use, attentional impairments, and crash involvement.

A potential selection bias in our sample may arise from the methods used to identify drivers under the influence of psychoactive substances. In Italy, involvement in a traffic crash with resulting injuries mandates a compulsory toxicological assessment, while roadside checks on circulating drivers are generally conducted randomly by law enforcement. In our study, clinical evaluations are carried out exclusively on individuals involved in traffic crashes who, following toxicological analyses, test positive for the use of psychoactive substances. Consequently, it is plausible that our sample may not adequately reflect the broader population of drivers operating vehicles under the influence of substances who are not intercepted by law enforcement, as compared to those involved in crashes where mandatory assessments are performed.

A third limitation is that a recruitment rate was not provided. Since participation in the study was voluntary, refusal to participate was rare and not systematically documented. As a result, the authors were unable to evaluate the reasons why some subjects declined participation.

Potential future developments of this study include the analysis of other factors potentially contributing to road crash involvement. A future study should consider individual and environmental factors. Among individual factors, the pattern of alcohol use, the presence of other psychoactive substances; among environmental factors the circumstances of the road crash, the time of the day, the presence of subjects injured in the road crash. The use of driving simulators to objectively assess the degree of impairment in driving ability among individuals who exhibit attention deficits and have a history of involvement in traffic crashes could be a future development of the study. Additionally, an area of particular interest could be the investigation of neurobiological correlates in individuals with substance use disorders who demonstrate attentional impairments, with a specific focus on their driving capabilities. In the end, based on our findings, preventive interventions could be designed to specifically address inattentiveness, which emerged as a key factor associated with road crash involvement. Such interventions might include cognitive and attentional training, behavioral programs focused on safe driving practices, and structured monitoring or follow-up plans. These approaches could potentially reduce the risk related to inattentiveness in drivers, regardless of sex.

However, given the exploratory nature of our study and the limited sample size, these strategies were not examined in detail in this paper. They should therefore be regarded as conceptual considerations that may warrant further investigation in future research with larger and more representative cohorts.

6. Conclusions

This study highlights the central role of inattentiveness and alcohol use as key predictors of road crashes. In our sample, inattentiveness was more strongly associated with crashes in the female subgroup, whereas blood alcohol concentration was more relevant among males. However, when both sexes were analyzed together, sex itself was not an independent predictor, indicating that the observed differences are explained by these underlying modifiable factors rather than by sex per se.

The predictive model showed higher accuracy in the female subgroup, suggesting that attentional measures may help identify at-risk drivers, although this finding should be interpreted cautiously due to the small female sample.

These results support focusing on modifiable factors, such as inattentiveness and alcohol use, when designing prevention strategies. Future studies with larger and more balanced samples are needed to confirm these associations and guide interventions to reduce crash risk.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration-of-interest-statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jflm.2025.103050.

References

1. Snenghi R, Forza F, Favretto D, et al. Underlying substance abuse problems in drunk drivers. *Traffic Inj Prev*. 2015;5:435–439. https://doi.org/10.1080/15389588.2014.968656.
2. Pawłowski W, Goniewicz K, Schwebel DC, Shen J, Goniewicz M. Road traffic injuries in Poland: magnitude and risk factors. *Eur J Trauma Emerg Surg*. 2019;45(5):815–820. https://doi.org/10.1007/s00068-019-01093-6.
3. NHTSA National Highway Traffic Safety Administration. Traffic crashes cost America $340 billion in. https://www.nhtsa.gov/press-releases/traffic-crashes-cost-america-billions-2019.2019; 2019. Accessed July 4, 2024.
4. World Health Organization (WHO). Road traffic injuries 2023. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries. Accessed June 30, 2024.
5. NIDA. Drugged driving drug facts. https://nida.nih.gov/publications/drugfacts/drugged-drivingon2024; 2019. Accessed June 18, 2024.
6. NHTSA National Highway Traffic Safety Administration. Drunk driving. https://www.nhtsa.gov/risky-driving/drunk-driving. Accessed June 30, 2024.
7. European Transport Safety Council. Progress in reducing drink-driving and other alcohol-related road deaths in Europe. https://etsc.eu/progress-inreducing-drink-driving-in-europe-2019/; 2019. Accessed June 30, 2024.
8. Dubois S, Mullen N, Weaver B, Bédard M. The combined effects of alcohol and cannabis on driving: impact on crash risk. *Forensic Sci Int*. 2015;248:94–100. https://doi.org/10.1016/j.forsciint.2014.12.018.
9. ISTAT. Indagine conoscitiva sulle dipendenze patologiche diffuse tra i giovani. https://www.istat.it/it/files//2021/05/IstatAudizioneCommissione_infanzia_adolescenza_27-maggio_2021.pdf; 2021. Accessed June 30, 2024.
10. Pasnin LT, Gjerde H. Alcohol and drug use among road users involved in fatal crashes in Norway. *Traffic Inj Prev*. 2021;22(4):267–271. https://doi.org/10.1080/15389588.2021.1887854.
11. Hareru HE, Negassa B, Kassa Abebe R, et al. The epidemiology of road traffic accidents and associated factors among drivers in Dilla Town, Southern Ethiopia. *Front Public Health*. 2022;10, 1007308. https://doi.org/10.3389/fpubh.2022.1007308.
12. Terranova C, Tagliabue M, Cona G, et al. Neurocognitive and behavioral markers in DUI recidivists. *Traffic Inj Prev*. 2019;20:S185–S189. https://doi.org/10.1080/15389588.2019.1659591.
13. Beccegato E, Ruggeri A, Montisci M, Terranova C. Driving license regranting in DUI subjects: road accident variables and predictive factors of substance use disorder. *Sci Prog*. 2021;104(3). https://doi.org/10.1177/00368504211033702, 368504211033702.

14. Elvik R. Risk of road accident associated with the use of drugs: a systematic review and meta-analysis of evidence from epidemiological studies. *Accid Anal Prev*. 2013; 60:254–267. https://doi.org/10.1016/j.aap.2012.06.017.
15. Uhl GR, Koob GF, Cable J. The neurobiology of addiction. *Ann NY Acad Sci*. 2019; 1451(1):5–28. https://doi.org/10.1111/nyas.13989.
16. Bjork J, Keyser-Marcus L, Vassileva J, Ramey T, Houghton D, Moeller F. Attentional function and inhibitory control in different substance use disorders. *Psychiatry Res*. 2022;313, 114591. https://doi.org/10.1016/j.psychres.2022.114591.
17. Abdulaal A, Tantawy A, Ibrahim O, Elbadry H, Hassan H. Cognitive dysfunction in adolescents with substance use disorder. *Middle East Curr Psychiatry*. 2023;30:291. https://doi.org/10.1186/s43045-023-00291-8.
18. Thoma R, Monnig M, Lysne P, et al. Adolescent substance abuse: the effects of alcohol and marijuana on neuropsychological performance. *Alcohol Clin Exp Res*. 2011;35(1):39–49. https://doi.org/10.1111/j.1530-0277.2010.01320.x.
19. Ramey T, Regier P. Cognitive impairment in substance use disorders. *CNS Spectr*. 2018;24(1):102–113. https://doi.org/10.1017/S1092852918001426.
20. Verdejo-Garcia A, Garcia-Fernandez G, Dom G. Cognition and addiction. *Dialogues Clin Neurosci*. 2019;21(3):239–248. https://doi.org/10.31887/DCNS.2019.21.3/gdom.
21. Bruijnen C, Dijkstra B, Walvoort S, et al. Prevalence of cognitive impairment in patients with substance use disorder. *Drug Alcohol Rev*. 2019;38(4):435–442. https://doi.org/10.1111/dar.12922.
22. Field M, Marhe R, Franken I. The clinical relevance of attentional bias in substance use disorders. *CNS Spectr*. 2013;19(3):225–230. https://doi.org/10.1017/S1092852913000321.
23. Yucel M, Lubman D, Solowij N, Brewer W. Understanding drug addiction: a neuropsychological perspective. *Aust N Z J Psychiatry*. 2007;41(12):957–968. https://doi.org/10.1080/00048670701689444.
24. Callan PD, Swanberg S, Weber SK, et al. Diagnostic utility of Conners Continuous Performance Test-3 for attention deficit/hyperactivity disorder: a systematic review. *J Atten Disord*. 2024;28(6):992–1007. https://doi.org/10.1177/10870547231223727.
25. Kato T, Ozone M, Kotorii N, et al. Sleep structure in untreated adults with ADHD: a retrospective study. *J Atten Disord*. 2023;27(5):488–498. https://doi.org/10.1177/10870547231154898.
26. Xu G, Strathearn L, Liu B, Yang B, Bao W. Twenty-year trends in diagnosed attention-deficit/hyperactivity disorder among US children and adolescents, 1997–2016. *JAMA Netw Open*. 2018;1(4), e181471. https://doi.org/10.1001/jamanetworkopen.2018.1471.
27. Aduen PA, Kofler MJ, Bradshaw CP, Sarver DE, Cox DJ. The role of top-down attentional control and attention-deficit/hyperactivity disorder symptoms in predicting future motor vehicle crash risk. *Neuropsychology*. 2020;34:894–905. https://doi.org/10.1037/neu0000707.
28. Terranova C, Cestonaro C, Cinquetti A, et al. Sex differences and driving impairment related to psychoactive substances. *Traffic Inj Prev*. 2024;25(4):553–561. https://doi.org/10.1080/15389588.2024.2325607.
29. Terranova C, Pozzebon F, Alessandro A, et al. Driving impairment due to psychoactive substances and attention deficit disorder: a pilot study. *Heliyon*. 2024; 10(2), e24083. https://doi.org/10.1016/j.heliyon.2024.e24083.
30. Society of Hair Testing. Consensus for the use of alcohol markers in hair for supporting the assessment of abstinence and chronic alcohol consumption. https://www.soht.org/images/pdf/Revision_2019_Alcoholmarkers.pdf; 2019. Accessed February 20, 2023.
31. Society of Hair Testing. SoHT consensus on drugs of abuse (doa) testing in hair. https://www.soht.org/images/pdf/Consensus_DoA_2021.pdf. Accessed February 20, 2024.
32. Conners CK. *Conners' Continuous Performance Test – 3rd Edition (CPT-3) Manual, Multi-Health Systems*. 2014. Toronto.
33. IBM Corp Released. *IBM SPSS Statistics for Windows, Version 28.0*. Armonk, NY: IBM Corp; 2021.
34. McManus B, Kana R, Rajpari I, Holm HB, Stavrinos D. Risky driving behavior among individuals with Autism, ADHD, and typically developing persons. *Accid Anal Prev*. 2024;195, 107367. https://doi.org/10.1016/j.aap.2023.107367.
35. Lynch JD, Tamm L, Garner AA, et al. Executive functioning as a predictor of adverse driving outcomes in teen drivers with ADHD. *J Atten Disord*. 2023;27(14): 1650–1661. https://doi.org/10.1177/10870547231197210.
36. Cinquetti A, Terranova C, Aprile A, Favretto D. Driving license regranting: hair EtG, serum CDT, and the role of sociodemographic and medicolegal variables. *Drug Test Anal*. 2023;15(9):953–961. https://doi.org/10.1002/dta.3426.
37. Polak K, Haug NA, Dillon P, Svikis DS. Substance use disorders in women. *Psychiatr Clin North Am*. 2023;46(3):487–503. https://doi.org/10.1016/j.psc.2023.04.006.
38. Kedia S, Mahmood A, Xie L, et al. Driving under the influence of substances and motor vehicle fatalities among older adults in the United States. *Traffic Inj Prev*. 2023;24(5):379–386. https://doi.org/10.1080/15389588.2023.2188435.
39. Lapham SC, Skipper BJ, Hunt WC, Chang I. Do risk factors for re-arrest differ for female and male drunk-driving offenders? *Alcohol Clin Exp Res*. 2000;24(11): 1647–1655. https://doi.org/10.1111/j.1530-0277.2000.tb01966.x.
40. Istituto Nazionale di Statistica (ISTAT). Smoking habits in the Italian population. http://dati.istat.it/Index.aspx?QueryId=15513. Accessed November 18, 2024.
41. Cornelius ME, Loretan CG, Jamal A, et al. Tobacco Product Use among adults – united States, 2021. *MMWR Morb Mortal Wkly Rep*. 2023;72:475–483. https://doi.org/10.15585/mmwr.mm7218a1.
42. Terranova C, Forza G, Beccegato E, et al. Cigarette smoking as a predictor of male DUI recidivism. *Int J Environ Res Public Health*. 2021;18(20), 10761. https://doi.org/10.3390/ijerph182010761.
43. Verplaetse TL, McKee SA. An overview of alcohol and tobacco/nicotine interactions in the human laboratory. *Am J Drug Alcohol Abuse*. 2017;43:186–196. https://doi.org/10.1080/00952990.2016.1189927.
44. Chen S, Yang P, Chen T, Su H, Jiang H, Zhao M. Risky decision-making in individuals with substance use disorder: a meta-analysis and meta-regression review. *Psychopharmacology*. 2020;237:1893–1908. https://doi.org/10.1007/s00213-020-05506-y.
45. Nochajski TH, Stasiewicz PR. Relapse to driving under the influence (DUI): a review. *Clin Psychol Rev*. 2006;26:179–195. https://doi.org/10.1016/j.cpr.2005.11.006.
46. Slobodin O, Davidovitch M. Gender differences in objective and subjective measures of ADHD among clinic-referred children. *Front Hum Neurosci*. 2019;13:441. https://doi.org/10.3389/fnhum.2019.00441.
47. Lee SH, Chia S, Chou TL, Gau SS. Sex differences in medication-naïve adults with attention-deficit/hyperactivity disorder: a counting Stroop functional MRI study. *Biol Psychol*. 2023;179, 108552. https://doi.org/10.1016/j.biopsycho.2023.108552.
48. Iqbal J, Huang GD, Xue YX, Yang M, Jia XJ. Role of estrogen in sex differences in memory, emotion and neuropsychiatric disorders. *Mol Biol Rep*. 2024;51(1):415. https://doi.org/10.1007/s11033-024-09374-z.
49. Faheem M, Akram W, Akram H, Khan MA, Siddiqui FA, Majeed I. Gender-based differences in prevalence and effects of ADHD in adults: a systematic review. *Asian J Psychiatr*. 2022;75, 103205. https://doi.org/10.1016/j.ajp.2022.103205.
50. Papalimperi AH, Athanaselis SA, Mina AD, et al. Incidence of fatalities of road traffic accidents associated with alcohol consumption and the use of psychoactive drugs: a 7-year survey (2011-2017). *Exp Ther Med*. 2019;18(3):2299–2306. https://doi.org/10.3892/etm.2019.7787.
51. Gjerde H, Normann PT, Christophersen AS, Samuelsen SO, Mørland J. Alcohol, psychoactive drugs and fatal road traffic accidents in Norway: a case–control study. *Accid Anal Prev*. 2011;43(3):1197–1203. https://doi.org/10.1016/j.aap.2010.12.03.
52. Cherpitel CJ, Ye Y, Bond J, Borges G, Monteiro M. Relative risk of injury from acute alcohol consumption: modeling the dose-response relationship in emergency department data from 18 countries. *Addiction*. 2015;110:279–288. https://doi.org/10.1111/add.12755.
53. Singh H, Kathuria A. Behind the wheel: probing into personality, skills, and driving behavior's role in bus rapid transit crashes. *Traffic Inj Prev*. 2024;25(4):604–611. https://doi.org/10.1080/15389588.2024.2322672.
54. Druta C, Kassing A, Gibbons R, Alden VA. Assessing driver behavior using shrp2 adverse weather data. *J Safety Res*. 2020;73:283–295. https://doi.org/10.1016/j.jsr.2020.03.013.
55. Stephens AN, Bishop CA, Liu S, Fitzharris M. Alcohol consumption patterns and attitudes toward drink-drive behaviours and road safety enforcement strategies. *Accid Anal Prev*. 2017;98:241–251. https://doi.org/10.1016/j.aap.2016.10.011.
56. Sundfør HB, Sagberg F, Høye A. Inattention and distraction in fatal road crashes - results from in-depth crash investigations in Norway. *Accid Anal Prev*. 2019;125: 152–157. https://doi.org/10.1016/j.aap.2019.02.004.