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Increased salience network connectivity in college students who engage in binge drinking: A resting state EEG study

Giorgia Allegrini [a], Elena De Rossi [a], Francesco Saverio Bersani [b], Giuseppe Alessio Carbone [c], Rita B. Ardito [d], Mauro Adenzato [d,*], Benedetto Farina [a], Claudio Imperatori [a]

[a] Experimental and Applied Psychology Laboratory, Department of Health and Life Sciences, European University of Rome, Rome, Italy
[b] Department of Medico-Surgical Sciences and Biotechnologies, Sapienza University of Rome, Rome, Italy
[c] Faculty of Psychology and Educational Sciences, University of Geneva, 40, Boulevard du Pont-d'Arve, Geneva 1205, Switzerland
[d] Department of Psychology, University of Turin, Turin, Italy

A R T I C L E I N F O

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A B S T R A C T

Background: Despite increasing awareness of the harmful consequences of binge drinking (BD), the underlying mechanisms, especially at the neurophysiological level, have yet to be fully elucidated. The main aim of the present research was to investigate the functional dynamics of the salience network (SN) in individuals with BD during the resting state using electroencephalography (EEG).
Methods: Forty-seven college students who engage in BD and 71 controls were enrolled. EEG data were analyzed using exact Low-Resolution Electromagnetic Tomography (eLORETA) software. *Results*: Compared to controls, individuals who engage in BD showed increased beta connectivity between the right insula and the left supramarginal gyrus ($T = 3.927$, $p = 0.008$). This connectivity pattern was also positively associated with BD severity ($rho = 0.424$, $p < 0.001$), even after controlling for potential confounding variables (i.e., age, sex, educational level, cannabis use severity, daily number of cigarettes, and general level of psychopathology).
Conclusion: This neural configuration may reflect enhanced connectivity between interoceptive and attentional-control circuits, resulting in increased neural sensitivity to internal and external alcohol-related cues.

1. Introduction

Binge drinking [BD; i.e., the excessive consumption of ethanol-containing beverages in a short period of time (D'Alessandro et al., 2023)] represents an alarming public health concern, particularly among young adults, with a prevalence ranging from 38 % to 47 % (Bartoli et al., 2014; Herrero-Montes et al., 2022; Nascimento et al., 2022). This pattern of excessive alcohol intake has been associated with a range of negative consequences at the cognitive (e.g., impairments in spatial working memory), emotional (e.g., depression symptoms over time, emotional appraisal/identification deficits), and behavioral (e.g., injures and vehicle accidents) levels (Carbia et al., 2018; Kuntsche et al., 2017; Martini et al., 2025), indicating that this problematic behavior merits serious attention.

Despite increasing awareness of the harmful sequelae of BD, the underlying mechanisms, especially the neurophysiological ones, have yet to be fully elucidated (Perez-Garcia et al., 2022; Tetteh-Quarshie and Risher, 2023), underscoring the need for investigation into its neural correlates. Among the various neuroimaging techniques, electroencephalography (EEG) is widely used to study alcohol- and binge drinking-related phenomena, given its high temporal resolution and sensitivity in detecting changes in brain activity and brain networks dynamics (Almeida-Antunes et al., 2021; Januszko et al., 2021; Jurado-Barba et al., 2020). For example, several resting state (RS) EEG studies have shown that BD severity is associated with several alterations in neural activity patterns, such as reduced alpha peak frequency (Affan et al., 2018) and/or increased midline delta (Courtney and Polich, 2010), frontal theta and beta activity (Affan et al., 2018), suggesting increased cortical excitability and possible impairments in information processing capacity among individuals who engage in BD (Lopez-Caneda et al., 2017).

Furthermore, EEG connectivity studies (Almeida-Antunes et al., 2022; Blanco-Ramos et al., 2022; Kim et al., 2020), which investigate the dynamic interactions between brain regions, have suggested that BD may be associated with functional alterations in large-scale neural networks. Within the framework of large-scale neural networks, previous

* Corresponding author.
E-mail address: mauro.adenzato@unito.it (M. Adenzato).

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functional magnetic resonance imaging (fMRI) reports have identified the salience network (SN) as a key neural system involved in the pathophysiology of BD (Arienzo et al., 2020; Gorka et al., 2018; Suarez-Suarez et al., 2025). The SN, which includes core regions such as the dorsal anterior cingulate cortex (dACC), anterior insula, supramarginal gyrus (SMG), and lateral prefrontal cortex (Pievani et al., 2017; Raichle, 2011), plays a critical role in detecting and integrating salient stimuli, modulating attention, and facilitating dynamic switching between other neural networks (Schimmelpfennig et al., 2023).

Dysregulation of this system has been associated with impaired decision-making, emotional dysregulation, and heightened sensitivity to reward cues, all of which are relevant to the development and maintenance of problematic drinking behaviors, including BD (Almeida-Antunes et al., 2022).

Despite this, to our knowledge, no study has used EEG connectivity to investigate the dynamic properties of the SN in individuals who engage in BD. Furthermore, although EEG connectivity in individuals with BD has been investigated during alcohol-related tasks (Almeida-Antunes et al., 2022; Blanco-Ramos et al., 2022), only one study to date has examined RS-EEG synchronization across brain regions (Kim et al., 2020). This experimental condition, which assess the intrinsic functional organization of the neural network (i.e., the spontaneous synchronization among brain regions), may be relevant for understanding the complex link between brain connections and cognition, emotion, and behavior (Anderson and Perone, 2018; Chen et al., 2025). In light of this background, the main aim of the present research was to investigate, using the EEG, the functional dynamics of the SN during the RS in individuals who engage in BD. According to previous fMRI (Arienzo et al., 2020) and EEG reports (Almeida-Antunes et al., 2022; Blanco-Ramos et al., 2022), we hypothesized that functional connectivity within SN hubs might be increased in individuals who engage in BD.

2. Material and methods

2.1. Participants

An a *priori* power analysis was performed using G*Power 3.1 software (Faul et al., 2009) to determine the required sample size for a *t*-test comparing EEG connectivity data between the BD and non-BD groups. The analysis indicated that, at a probability level of 0.05, a sample size of 100 was required to achieve satisfactory statistical power (1–β= 80 %) with an effect size of d= 0.606 in a two-sided test (allocation ratio N2/N1 = 2; i.e., 67 vs 33). This effect size was estimated based on a previous RS-EEG study (Kim et al., 2020), which identified distinct connectivity patterns in individuals with BD compared to non-BD participants and reported t-values ranging from 1.78 to 3.00 [mean t = 2.50, Cohen's d conversion= 0.606; (Lakens, 2013)].

Participants were recruited via an online survey distributed through web-based platforms on the university campus. The survey collected information on inclusion/exclusion criteria, socio-demographic variables (including biological sex and age), and the target study variables (see the "self-report measures" section). Respondents accessed the questionnaire by scanning a QR code or clicking a web link on their chosen device (e.g., smartphone, tablet, or laptop). All participants took part voluntarily and anonymously, provided written informed consent before participating, and received no compensation.

Recruitment lasted from April 2024 to January 2025. Inclusion criteria for being included in the current study were: i) self-reported use of alcoholic beverages with some frequency, i.e., a score ≥ 1 on item#1 of the Alcohol Use Disorders Identification Test - AUDIT scale (Saunders et al., 1993): "*How often do you have a drink containing alcohol?*"); ii) age between 18 and 34 years; iii) both sexes; iv) right-handedness, i.e., Laterality Quotient ≥ 50, (Oldfield, 1971), v) native Italian speakers. The following exclusion criteria were applied: i) current and/or past self-reported psychiatric and/or neurological diagnoses; ii) self-reported consumption of psychoactive drugs and/or illicit substances in the 14 days prior to EEG recording.

One hundred and seventy college students were assessed for eligibility. One hundred and eighteen respondents (90 females, mean age: 21.75 ± 2.56 years) met the eligibility criteria and participated in the present research. The current study is part of a larger research project investigating the risk factors for depression, supported by the Italian Ministry for University and Research. The individuals included in the present research represent a subsample of participants from a study previously published by our research group (Imperatori et al., 2025). Ethical approval for this study was granted by the Ethics Review Committee of the European University of Rome (Prot. No. 12/2023), in accordance with the ethical standards established by the Declaration of Helsinki.

2.2. Self-report measures

In the present study, all participants completed the AUDIT-3 (Bush et al., 1998), the Brief Symptoms Inventory (BSI; Derogatis and Melisaratos, 1983), and the Cannabis Abuse Screening Test (CAST; Legleye et al., 2007) to assess BD, general level of psychopathology, and cannabis use severity, respectively. Participants were also asked to provide the following sociodemographic and clinical data: age, biological sex, educational level (i.e., bachelor's degree), and daily number of cigarettes.

The AUDIT-3 is the third item (i.e., "*How often do you have six or more drinks on one occasion?*" Response options: never= 0, less than monthly= 1, monthly= 2, weekly= 3, daily or almost daily= 4) of the AUDIT (Saunders et al., 1993). It is considered a suitable tool for classifying individuals who engage in BD, without differentiating by sex (Cortes-Tomas et al., 2016). In the current study, a cut-off of ≥ 1 was used to define BD and non-BD groups. This cut-off has previously been used in Italian samples (Mereu et al., 2021) and is characterized by high sensitivity and excellent specificity (Bush et al., 1998; Cortes-Tomas et al., 2016), especially in detecting BD (Cortes-Tomas et al., 2016).

The BSI is a 53-item self-report tool widely used to assess overall psychopathological distress (Derogatis, 2017). It evaluates nine core clinical domains (e.g., depression and anxiety) and provides the global severity index (GSI), which is the most sensitive overall index of general psychopathology (Derogatis, 2017). Items are rated on a 5-point Likert scale (from 0 = "not at all" to 4 = "extremely"), with higher values indicating greater symptom severity. The BSI is characterized by robust psychometric properties (Derogatis, 2017). In the current research, the Italian version of the BSI (Adawi et al., 2019) was used showing satisfactory internal consistency (α= 0.96).

The CAST (Legleye et al., 2007) is a 6-item self-report tool widely used to assess problematic cannabis use over the past 12 months (Casajuana et al., 2016). Items are rated on a 5-point Likert scale, with higher scores indicating greater levels of problematic cannabis use. The scale is characterized by satisfactory psychometric properties, including a stable factorial structure (Legleye et al., 2017). In the current study, the Italian version of the CAST was used (Bastiani et al., 2013), and Cronbach's α in our sample was 0.69.

2.3. EEG recordings, processing and analysis

During the week following enrolment, participants underwent an eyes-closed RS-EEG recording in the university laboratory. Students were requested to refrain from consuming alcohol or caffeine for at least four hours before the EEG recording. The EEG session lasted at least five minutes and was conducted using 64 passive electrodes positioned according to the international 10–10 system, connected to multi-channel amplifiers (BrainAmp, BrainProducts GmbH, Gilching, Germany). The ground and reference electrodes were placed at Fpz and FCz, respectively. Impedance was kept below 20 kΩ, and signals were acquired at a sampling frequency of 500 Hz.

EEG raw data were processed offline using the EEGLAB toolbox in MATLAB (version 2022.1; Delorme and Makeig, 2004). Data were down-sampled to 256 Hz, band-pass filtered between 1 and 40 Hz, and re-referenced to the average. After a preliminary visual examination and removal of the main marked artifacts (e.g., muscle activity), Independent Component Analysis (ICA) was performed using the infomax decomposition algorithm to remove other artifacts. Noisy components were removed after careful visual evaluation of spectral and topographical features, preserving maximal physiological variance for each participant (e.g., Assenza et al., 2024; Chang et al., 2024; Lanzone et al., 2022). A three-dimensional spherical spline interpolation was also performed on most channels affected by artifacts (Ferree, 2006).

Artifact-free EEG data were divided into 4-second epochs, with a minimum of 50 epochs per participant (Miljevic et al., 2022), and analyzed using the Exact Low-Resolution Electromagnetic Tomography software (eLORETA; Pascual-Marqui et al., 2011), a widely recognized device for detecting electrophysiological activity (Asadzadeh et al., 2020; Halder et al., 2019; Jatoi et al., 2014) and investigating the functional dynamics of large-scale brain networks (Liu et al., 2018). Despite its limited spatial resolution, eLORETA provides an accurate reconstruction of electrocortical activity using a three-dimensional, linear, distributed non-inverse norm solution (Canuet et al., 2012).

Following previous eLORETA studies (Carbone et al., 2025; De Rossi et al., 2025; Massullo et al., 2022; Zinn et al., 2016), SN connectivity was investigated identifying seven regions of interest (ROIs; Supplementary Figure 1). ROIs were reconstructed using the "ROI-maker#1" option based on Montreal Neurological Institute (MNI) coordinates, with each ROI consisting of the single nearest voxel to the corresponding SN node (e.g., Canuet et al., 2011; de la Salle et al., 2016; Kitaura et al., 2017).

Functional connectivity within SN hubs was computed using the lagged phase synchronization (LPS) algorithm (Pascual-Marqui et al., 2011), which removes instantaneous zero-lag contributions and minimizes non-physiological artifacts, making it a widely adopted index for EEG connectivity evaluation (Hata et al., 2016; Olbrich et al., 2014). Based on the normalized Fourier transform, LPS quantifies the similarity of EEG patterns in certain frequency bands, ranging from 0 (no synchrony) to 1 (maximum synchrony). In the current research, the following frequencies were considered: delta (1–4 Hz), theta (4.5–7.5 Hz), alpha (8–13 Hz), and beta (13.5–30 Hz) bands.

2.4. Statistical analysis

EEG SN connectivity analysis was performed by comparing the BD and non-BD groups using the non-parametric mapping procedure available in the eLORETA package. This statistical method is based on Fisher's permutation and applies a non-parametric randomization procedure to correct for multiple testing (Nichols and Holmes, 2002). In more details, this approach uses 5000 data randomizations to define the critical probability threshold of T-values corresponding to adjusted *p*-values (i.e., corrected for multiple testing among all connections, in each frequency band, without the need to assume Gaussianity). This procedure is commonly used in eLORETA reports and is considered a suitable strategy for controlling the multiple testing issue (see Hata et al., 2016 for technical details). The eLORETA software also calculates effect size thresholds for t-statistics corresponding to Cohen's d values (Cohen, 1988): small = 0.2, medium = 0.5, large = 0.8.

Given the non-normal distribution (i.e., Shapiro-Wilk test <0.05) of several variables (e.g., age and GSI), the Kolmogorov-Smirnov (KS) Z test or the Chi-squared test with Yates' correction were used to evaluate between-group differences for continuous and categorical variables, respectively.

As a sensitivity analysis, a Kolmogorov–Smirnov Z test was performed to investigate between-group differences in significant SN connectivity patterns detected by eLORETA. These patterns were analyzed using standardized residuals to control for potential confounding variables (i.e., GSI, age, sex, educational level, CAST total score, and daily number of cigarettes). As a further sensitivity analysis, an eLORETA comparison was also performed using a stricter criterion for BD frequency (i.e., AUDIT-3 $\geq$ 2).

Lastly, as a supplementary analysis, to measure BD also as a continuous variable, the association between AUDIT-3 scores and any significant EEG connectivity pattern, was analyzed using Spearman's *rho* correlation coefficient, with GSI, age, sex, educational level, CAST total score, and daily number of cigarettes as covariates (i.e., standardized residual). IBM SPSS Statistics for Windows, version 18.0 (Chicago, USA), was used for the statistical analyses.

3. Results

According to the AUDIT-3 cut-off (i.e., $\geq$ 1), 47 participants were included in the BD group and 71 in the non-BD group. The two groups did not differ significantly in socio-demographic variables. Compared to non-BD participants, individuals with BD reported higher levels of general psychopathology. The daily number of cigarettes was also significantly higher in the BD group than in the non-BD group. Full between-group differences are reported in Table 1.

Regarding EEG data, a qualitative visual inspection of the raw EEG data revealed no evidence of unusual patterns, such as sleepiness or epileptic discharges. The average number of epochs analyzed for the BD and non-BD groups was 66.85 ± 6.70 and 67.45 ± 6.67, respectively (KS= 0.51; p = 0.956). The average number of interpolated channels for the BD and non-BD groups was 0.89 ± 1.13 and 0.69 ± 0.94, respectively (KS =0.50; p = 0.967).

The eLORETA thresholds (T) for significance, corrected for multiple comparisons, were T = ±3.857 (corresponding to $p < 0.01$) and T = ±3.380 (corresponding to $p < 0.05$). Effect sizes for T-thresholds were 2.154, 5.385, and 8.616, corresponding to small, medium, and large effect sizes, respectively. A significant difference between groups was observed in the beta band (T = 3.927, p = 0.008). Specifically, compared to non-BD participants, individuals who engage in BD showed increased beta LPS between the right insula and the left supramarginal gyrus (SMG) (Fig. 1). After controlling for GSI, age, sex, educational level, CAST total score, and daily number of cigarettes, this connectivity pattern remained significantly different between groups (KS = 1.078, p = 0.001) and was significantly correlated with AUDIT-3 scores (*rho*= 0.424, $p < 0.001$, see Supplementary Figure 2). No other significant differences were detected (see Supplementary Figure 3 shows the complete SN T-values matrix for the between-groups comparison).

This connectivity pattern was also significant when a stricter criterion for BD frequency (i.e., AUDIT-3 $\geq$ 2) was applied (see

Table 1
Between-group differences.

	BD (N = 47)	Non-BD (N = 71)	Statistic Test	p-value
Age – M ± SD	21.28 ± 2.51	22.07 ± 2.56	KS = 1.17	0.129
Females – N (%)	32 (68.1)	58 (81.7)	CHI^2 = 2.89	0.089
Daily cigarettes – M ± SD	4.11 ± 4.76	2.04 ± 4.39	KS = 1.55	0.016
CAST total score – M ± SD	0.87 ± 2.07	0.13 ± 5.33	KS = 0.76	0.615
Bachelor's Degree – N (%)	13 (27.7)	21 (29.6)	CHI^2 = 0.05	0.822
AUDIT#3 – M ± SD	1.55 ± 0.62	0.00 ± 0.00	KS = 5.32	< 0.001
BSI-GSI – M ± SD	0.97 ± 0.55	0.74 ± 0.57	KS = 1.53	0.019

Abbreviation: BD= Binge drinking; CAST= Cannabis Abuse Screening Test; AUDIT#3 third item of the Alcohol Use Disorders Identification Test; BSI-GSI= Brief Symptom Inventory - Global Severity Index; KS= Kolmogorov-Smirnov test.

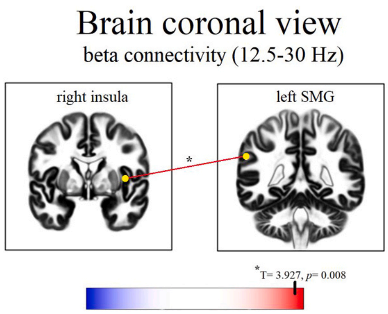

Fig. 1. eLORETA functional connectivity results for the between-groups comparison (BD vs. non-BD) in the beta frequency band. Compared to non-BD participants, BD individuals showed increased beta connectivity (red line) between the left supramarginal gyrus (SMG) and the right insula. The threshold value (T) for statistical significance is reported at the bottom of the figure.

Supplementary Figure 4). According to this cut-off, 23 participants were included in the BD group and 73 in the non-BD group (i.e., AUDIT-3 = 0).

4. Discussion

In the present study, we investigated RS-EEG functional connectivity within the SN in individuals who engage in BD. Compared to controls, BD participants showed increased beta synchronization between the right insula and the left SMG. This connectivity pattern was also positively associated with BD severity, even when controlling for potential confounding variables (i.e., age, sex, educational level, cannabis use severity, daily number of cigarettes, and general level of psychopathology). This suggests that enhanced beta synchronization within these SN hubs may represent a specific electrophysiological marker of BD pathophysiology.

RS beta hyper-synchronization has been conceptualized as a signature of brain hyper-excitability (Lee et al., 2021; Park et al., 2018) and reduced inhibitory control (Ding et al., 2023; Imperatori et al., 2015; Koelsch et al., 2008). Indeed, increased RS beta activity and connectivity have been detected in several clinical pictures characterized by impulsivity and reduced behavioral control, alcohol-related problematic drinking behaviors (Almeida-Antunes et al., 2021; Jurado-Barba et al., 2020), other substance use disorders (Liu et al., 2022), and binge eating disorder (Imperatori et al., 2015). Notably, at the neurochemical level, an association between increased RS beta coherence and reduced midbrain and striatum dopamine levels has been previously reported (George et al., 2013; Sharott et al., 2005; Waninger et al., 2020). According to the reward deficiency model of addiction (Blum et al., 2000), dysfunction in the brain reward cascade, resulting from a combination of genetic and environmental factors, has been shown to promote abnormal cravings for rewarding stimuli thereby increasing the risk of developing various addictive, impulsive, and compulsive disorders (Bowirrat and Oscar-Berman, 2005; Martins et al., 2022).

In addition, repeated exposure to addictive substances can sensitize specific brain circuits and amplify the incentive salience attributed to drug cues (Robinson and Berridge, 1993, 2025; Vollstadt-Klein et al., 2012). In BD, enhanced salience attributed to alcohol cues has recently been reported to be associated with increased beta-band connectivity at the electrophysiological level (Almeida-Antunes et al., 2022).

Given this background, the observed connectivity pattern in the BD group might reflect an electrophysiological configuration associated with heightened sensitivity to alcohol-related stimuli, which could in turn be linked to a reward deficiency. In line with this possibility, the SN is a crucial brain system involved in the detection of salient stimuli, including rewarding stimuli, and is known to be altered in addiction (Cushnie et al., 2023) and BD (Arienzo et al., 2020; Gorka et al., 2018; Suarez-Suarez et al., 2025). Of relevance, both the right insula and the left SMG (i.e., the two SN nodes that exhibited increased beta connectivity in individuals who engage in BD) have been found to show altered connectivity in alcohol-related problems (e.g., Al-Khalil et al., 2021; Halcomb et al., 2019; Le et al., 2022) and, more generally, in addiction (Cushnie et al., 2023; Lee et al., 2022, 2024).

The right insula is involved in interoceptive awareness, evaluation of bodily and emotional states, and craving related processes (Naqvi and Bechara, 2010) integrating visceral and somatic information to generate subjective representations of internal states and motivational urges, including those related to alcohol (Garavan, 2010; Ray et al., 2010). The left SMG is also an important SN hub, playing a key role in integrating perceptual/sensory information (Braga et al., 2013; Michaelis et al., 2020) and in modulating externally oriented bottom-up attentional mechanisms towards context-relevant stimuli (Ciaramelli et al., 2008; Uncapher and Wagner, 2009).

Within this framework, increased RS beta coherence between the right insula and SMG may be interpreted as a stronger coupling between interoceptive and attentional-control circuits, potentially reflecting and/or contributing to heightened neural sensitivity to both internal and external alcohol-related cues.

In relation to alcohol use disorder and BD, the current findings are consistent with previous brain connectivity studies (Arienzo et al., 2020; Syan et al., 2023), which suggest that the amplified salience attributed to drug cues can be observed not only during exposure to alcohol cues, but also during RS (i.e., during the experimental condition reflecting the intrinsic functional organization of the brain; Anderson and Perone, 2018; Chen et al., 2025). Although this interpretation is intriguing, it remains largely speculative and should be treated with caution, as the present study included neither an alcohol cue reactivity task nor an examination of dopaminergic function.

Notably, in the current report, we did not find significant associations between BD and other SN nodes (e.g., the dACC), nor in frequency bands other than beta, as previously reported (Gorka et al., 2018; Kim et al., 2020; Suarez-Suarez et al., 2025). The inconsistencies between earlier studies and the current findings could be due to differences in study design, including the choice of imaging modality (EEG vs. fMRI) and connectivity measures (LPS vs. imaginary coherence).

Several limitations should also be noted when interpreting the study results. First, the cross-sectional design precludes establishing causality among the observed variables, and future longitudinal studies are needed. Second, although participants reporting psychiatric conditions were excluded and we controlled for the general level of psychopathology (i.e., the GSI scores), a full structured clinical interview was not conducted. Third, although the eLORETA is a suitable tool for estimating cortical, limbic, and paralimbic electrophysiological activity (Mulert et al., 2004), it has limited spatial resolution for detecting subcortical regions (e.g., the ventral tegmental area and the striatum) implicated in BD pathophysiology (Cservenka and Brumback, 2017). Fourth, it is important to note that several BD-related variables (e.g., drinking speed, number of drinks per occasion, age of drinking onset, time since last alcohol consumption and BD episode) and other potentially relevant vulnerability factors (e.g., family history of alcohol/substance use) were not assessed.

Lastly, only the RS condition was evaluated. Thus, SN-related EEG connectivity patterns associated with alcohol-related cues and natural reward stimuli in BD should be further investigated. Furthermore, although we performed a sensitivity analysis using a stricter criterion for BD frequency (i.e., AUDIT-3 $\geq$ 2), these findings should be replicated in a larger sample of individuals with BD. Moreover, as increased beta connectivity has been observed in various impulsivity- and addiction-related conditions, future studies should examine whether this electrophysiological pattern represents a general marker of disinhibition and reward-related vulnerability or a specific feature of BD.

Despite these limitations, the current findings may provide new insights into the neurophysiological mechanisms underlying BD in young adults, suggesting potential links between RS-SN hyper-synchronization, reduced dopaminergic transmission, and heightened sensitivity to alcohol-related stimuli.

In conclusion, increased beta connectivity between the right insula and the left SMG was observed to constitute a distinct electrophysiological pattern associated with BD, and these results may also have clinical applications. Altered neural circuits in young adults with BD may reveal early vulnerability markers for problematic forms of alcohol use and inform preventive and therapeutic interventions designed to restore functional connectivity in large-scale networks (Camchong et al., 2023; Padula et al., 2022).

CRediT authorship contribution statement

Rita B. Ardito: Writing – review & editing, Funding acquisition, Conceptualization. **Mauro Adenzato:** Writing – review & editing, Methodology, Conceptualization. **Benedetto Farina:** Writing – original draft, Methodology, Conceptualization. **Claudio Imperatori:** Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Giorgia Allegrini:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Elena De Rossi:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Francesco Saverio Bersani:** Writing – review & editing, Methodology, Conceptualization. **Giuseppe Alessio Carbone:** Writing – review & editing, Methodology, Conceptualization.

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Declaration of Competing Interest

The authors declare no conflicts of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.drugalcdep.2026.113098.

Data Availability

Aggregated data are available from the last author upon request.

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