Title: The Impact of Alcohol on Brain Response in Social Context: A Hyperscanning Alcohol-Administration Trial

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Highlights

- The study combines experimental alcohol-administration and EEG hyperscanning to capture acute alcohol effects on interacting brains
- Findings indicate significant correlations in event-related potential (ERP) performance monitoring signatures among socially engaged dyads
- Alcohol intoxication selectively reduced social (i.e., observational) elements of performance monitoring during task performance in novel social context
- Findings offer support for core social dimensions of human cognition, and further indicate potential mechanisms via which alcohol might modulate social experience

Keywords

Alcohol administration, Social cognition, EEG hyperscanning, Event-related potentials (ERPs), Feedback effects.

Abstract

Evidence for the integration of alcohol into social life dates to the beginning of recorded history. Humans' tendency to combine social interaction with alcohol has been attributed to alcohol's ability to shift social perception, with behavioral research suggesting alcohol fosters social connection and diminishes perceived social threat. Yet the acute effects of alcohol on brain responses in social context are as yet unexplored. Combining experimental alcohol-administration with an EEG hyperscanning paradigm, the current study examines the effect of alcohol on evaluation of self- and other-linked performance. Social drinkers (N=128) were administered either an alcoholic (target BAC .08%) or control beverage in pairs. Dyads engaged in a gambling task while event-related potential Feedback Effects (FEs) to wins and losses were assessed simultaneously in both participants. Findings indicated a significant correlation in FEs among players and observers. Results further revealed alcohol effects that emerged specifically in the social domain, with alcohol intoxication significantly reducing the magnitude of FEs among observers paired with a stranger. In contrast, alcohol's impact on FEs was non-significant when participants observed a familiar partner, as well as when participants were actively engaged in playing. Taken together, findings provide evidence for core social (e.g., observational) dimensions of human cognition and further offer clues surrounding neural pathways supporting the widespread integration of alcohol into social life.

Introduction

"The culture of drink endures because it offers so many rewards: confidence to the shy, clarity for the uncertain, solace to the wounded and lonely, and above all, the elusive promises of friendship and love"

—Pete Hamil, *A Drinking Life: A Memoir*[1]

"An intelligent man is sometimes forced to be drunk to spend his time with fools."

—Ernest Hemingway, *For Whom the Bell Tolls*[2]

The human capacity for navigating expansive social networks is arguably among the species' greatest strengths.[3,4] Human social structures have facilitated the pooling of labor and exchange of ideas on an unprecedented scale, permitting us to conquer environmental challenges, enlarge the species, and bring into being marvels of technology.[5–7] Yet the same social world that permits international space stations simultaneously presents formidable challenges.[3] Whereas humans' close primate relatives coexist in small societies,[8–10] humans are confronted daily with a comparatively expansive social group, exposed to the unpredictable actions of a network of unknown others.[11,12] Some researchers have gone so far as to posit that the human brain has evolved as a uniquely social organ.[8,13,14] In light of this, core to the understanding of human strength is the understanding of factors that promote humans' ability to cope in an environment comprising unfamiliar people with whom they are nonetheless enmeshed and interdependent.[15–17]

Among the most widely employed tools for coping in these heterogeneous social contexts can be found in the drug alcohol.[18,19] Evidence for the integration of alcohol into social life dates to the beginning of written history,[20–22] with current studies indicating that between 13% and 26% of social interactions conducted during leisure time feature alcohol consumption.[23] Reward from alcohol is intensified when consumed in company versus alone,[24–26] social enhancement is the most widely endorsed reason for consuming alcohol,[27] and contexts featuring unfamiliar individuals (e.g., bars and large parties) have long been associated with particularly heightened—and sometimes hazardous—patterns of consumption.[28–32] Indeed, alcohol's longstanding and pervasive role in human socialization is intertwined with the fact that it has also been identified as the drug causing the most aggregate harm across both individual users and society.[33] Thus, identifying brain mechanisms promoting alcohol's as yet mysterious socially cohesive properties has emerged as a research priority.

Yet a range of challenges has emerged in the study of acute drug effects on the human brain, particularly for research seeking to model these as they might manifest in social context. In particular, direct vasoactive effects of alcohol confound signals associated with benchmark imaging modalities such as functional magnetic resonance imaging (fMRI), which examine blood flow as a proxy for brain activity.[34–37] Further, alcohol has psychoactive properties that exaggerate reactivity to immediate environmental cues,[38–42] thus presenting challenges for modalities such as fMRI and positron emission tomography (PET) that feature atypical recording environments (e.g., noisy, supine, enclosed). Thus, no research to date has explored brain effects of alcohol in the context of in-vivo social contact, limiting understanding of addictions' underpinnings as well as our broader knowledge of how humans navigate the social world surrounding them.

Over the past two decades, neuroscientific methods featuring multi-participant recording arrays have emerged, permitting the scanning of two brains concurrently—a technique referred to as *hyperscanning*—in social contexts.[43–50] This advancement offers critical insights into the neural mechanisms of social perception and coordination that single-subject recordings cannot provide. In fact, evidence for the utility of this socially informed neuroscience has accumulated, with studies suggesting that the "mere-presence" of another individual significantly alters both resting state and task-evoked brain activity.[42,44,47–51] These studies have demonstrated that interpersonal contexts, such as cooperative gambling tasks and competitive prisoner's dilemma tasks, reliably evoke shared neural dynamics linked to social coordination.[51–55] Among the most widely employed recording modalities within this literature is electroencephalography (EEG), which has the advantage of offering a relatively unconstrained recording environment, permitting in-vivo social contact between participants, while further circumventing alcohol-specific recording artifacts by offering a direct measure of brain activity (versus an indirect measure based on blood flow).[43,44,47,48,60–62] Segments of the continuous EEG signal can further be yoked to elements of the task environment, yielding components known as event-related potentials (ERPs), which provide temporally precise and functionally meaningful measures of brain activity.[63,64] Hyperscanning approaches that specifically measure ERPs permit in-vivo social contact while also holding constant key elements of the stimulus space, so providing interpretable individual brain responses in the context of social activities that mirror real-world drinking settings (e.g., television watching; gaming). Thus, while early hyperscanning studies historically focused on inter-brain coupling metrics derived from free-form EEG signals,[65–68] hyperscanning research has since expanded to include research examining ERP metrics derived from two brains in tandem, enhancing the interpretability by holding constant task environment and thus context for assessment. As described next, hyperscanning ERP research has begun to examine how feedback-related processing and performance monitoring unfold in cooperative and competitive tasks, demonstrating shared neural responses between actors and observers. Yet, how psychoactive substances such as alcohol may modulate these neural dynamics in social contexts remains unexplored.

Of particular utility for studying the neural underpinnings of how we evaluate both ourselves and others in social context are ERP responses associated with performance monitoring. These include inherent responses to our own behavior (e.g., making a motor error; the so-called Error-Related Negativity (ERN)) as well as responses to feedback about performance or task outcomes, such as losses and wins in a gambling task (Feedback-Related Negativity or FRN; Reward Positivity or RewP).[69–75] Performance monitoring ERPs have been linked to phasic changes in mesencephalic dopamine signals affecting activity in a brain network, including the anterior cingulate cortex, medial frontal cortex, and striatum, which is responsible for updating behavior in response to feedback that deviates from expectations, whether in a positive or negative direction.[71,76,77] The difference between the response to losses and negative feedback, which elicits more negativity (FRN), and the response to gains and positive feedback (RewP) is maximal over medial frontal scalp locations around 250 ms after the presentation of the feedback/outcome. Strikingly, multiple ERP hyperscanning studies have reported that this same type of *feedback effect* (FE)[60] can be elicited not only in those actively involved in tasks but also among observers with no direct role in task performance, showing that, in social contexts, people engage their own reinforcement-learning systems in response to others' performance.[55,74,78,79]

The degree to which people engage in performance monitoring, as either an actor or an observer, is affected by the task context and the nature of the interpersonal relationships represented therein.[80] Important, the behavior of unfamiliar interaction partners (i.e., strangers) tends to evoke a heightened level of scrutiny,[81] particularly in situations involving mutually-dependent losses and gains. For example, when an unfamiliar colleague makes a visible mistake during a shared task, we may react with internal scrutiny or discomfort, whereas a similar mistake from a close friend might be met with amusement or empathy. Reflecting the context-dependent nature of performance monitoring processes, FEs are larger for outcomes with more motivational significance,[76] and FE size is positively correlated with dispositional anxiety, consistent with claims that these responses arise from the engagement of adaptive control processes in the face of uncertainty about actions and their outcomes.[83] Correspondingly, a number of ERP hyperscanning studies have found that the presence of an observer increases FEs in actors,[84] especially under competitive conditions.[85] FEs are on average smaller for observers than for actors,[86,87] at times emerging as pronounced[47,50,88] and at times minimal,[86,87] and these *observer* FEs (*o*FEs) have been shown to reflect the individual's evaluation of the outcome from their own perspective.[47,89,90] Carp et al.[91] further found that lower perceived similarity between observer and actor is correlated with larger *o*FEs, consistent with the idea that we have evolved to judge the actions of strangers through a framework of vigilance,[81] aiding us in the compilation of evidence surrounding the unknown other's characteristics to help us inform decisions about whether to cement new social ties or instead invest resources elsewhere.[82]

These dynamics align with tenets of the social-attributional model,[39] which proposes that individuals engage heightened social evaluative vigilance when interacting with unfamiliar others as part of an adaptive strategy to manage the uncertainties and potential social threats posed by strangers. This vigilance involves increased monitoring of others' behaviors and heightened sensitivity to social cues, which can contribute to social anxiety or evaluative concerns in novel settings. Building on this, a later expansion and elaboration of this framework (the "social-cognitive model"[42]) posits that alcohol reduces perceived social threat and attenuates evaluative monitoring, particularly in contexts of social uncertainty, such as interactions with strangers. Together, these models suggest that alcohol may play a socially buffering role by dampening the cognitive and affective processes underlying social vigilance, thereby facilitating smoother social interactions and reducing evaluative stress in unfamiliar social environments. The widespread integration of alcohol into social life, particularly spaces featuring stranger interaction, may therefore be attributable to alcohol's ability to silence the internal judge, reducing the cognitive demands associated with performance evaluation in social context and thus leaving open the potential for a more cohesive social sphere.[3,92–95] This theoretical perspective informs our hypothesis that alcohol's effects on performance monitoring will be most pronounced in stranger interactions, where evaluative concerns are elevated, and will be diminished in interactions between friends, where trust and familiarity often preclue the need for such vigilance.

Although alcohol's general dampening effect on performance monitoring ERPs (e.g., ERN) has been established (see Fairbairn, Federmeier, & Kang, 2021, for a meta-analysis[96]), all of the previous studies used a single-person paradigm, and whether these effects vary across social contexts remains unknown. Given the impact of social factors on attention and other aspects of cognitive functioning, effects of alcohol on processes like performance monitoring may well be different in social compared to non-social contexts, with important implications for understanding patterns of alcohol use and corresponding risks. Thus, ERP hyperscanning offers a unique advantage to the study of alcohol's effects by (a) incorporating in-situ social contexts, in which participants can play multiple roles, and (b) allowing the simultaneous measurement of functionally well-characterized, task-evoked responses. In this regard, the present study is the first to combine drug-administration methods with an ERP hyperscanning paradigm to concurrently examine FEs in actors and observers, exploring alcohol's influence on evaluative processes in social contexts. Uniquely, while prior research has investigated the effects of cannabis in naturalistic social settings,[97] to our knowledge, no studies have applied EEG hyperscanning to examine alcohol's impact on brain processes during live social interactions.

The primary objective of the current study was twofold: (1) to examine whether acute alcohol intoxication selectively attenuates FEs in social contexts characterized by heightened evaluative demands—specifically, during observation of a stranger's performance; and (2) to assess whether this modulation differs across social roles, by evaluating alcohol's effects on neural responses in both active task performers (players) and passive observers wihin dyads composed of either friends or strangers. We hypothesized that alcohol's impact on FEs would be non-significant among friends, where broader social evaluative effects are subdued. Conversely, we anticipated that alcohol would substantially reduce the magnitude of the FE among strangers, influencing both task performers and observers.

Materials and Methods

Ethics Statement. Written informed consent was obtained from all participants prior to their inclusion in the study. The privacy rights of human subjects were strictly observed throughout the research process. The study protocol was reviewed and approved by the Institutional Review Board (IRB) of the University of Illinois at Urbana-Champaign, under the approval number 16263.

Participants consisted of 128 healthy drinkers ages 21-30 recruited from the local community. A sensitivity power analysis using the *simr*[98] package in R revealed that this sample size was large enough to detect a small-medium interaction effect assuming an alpha level of 0.05 and 80% power. These participants constitute a subset of those enrolled in a large project focused on alcohol reinforcement in unfamiliar social context who also underwent hyperscanning EEG procedures during the time period from 10/2021-2/2023 (ClinicalTrials NCT03449095). To meet eligibility, participants had to identify at least one same-gender friend—someone with whom they considered themselves to have been friends of at least 6 months—who also met inclusion criteria for the study. For the present study we selected dyads wherein both members yielded at least 30 usable trials for all critical conditions (player win and loss and observer win and loss). Dyads were fully counterbalanced for alcohol and relationship condition. Exclusion criteria included medical conditions for which alcohol consumption is contraindicated; recent use of psychoactive substances (e.g., use of hallucinogens more than five times or any use of opioids, benzodiazepines, or other depressants/sedatives in the past 30 days); current use of medications—excluding prescription eye drops or ADHD medications—that could not be withheld for 24 hours; pregnancy in females; a history of major psychiatric diagnosis or severe alcohol use disorder; and a history of skull fracture. Please see Table 1 for full descriptive statistics of the participant sample, including sociodemographic characteristics and alcohol and other substance use history.

Following successful completion of screening, two friend dyads were invited to the laboratory for simultaneous beverage-administration sessions. On the day of the experimental session, half of participants were randomized to complete experimental procedures in the company of their own friend whereas the other half were assigned to complete procedures in the company of the friend of the other participant. All participants were casually and informally introduced at study outset to ensure no prior acquaintance in the stranger condition, with procedures carefully designed to maintain unfamiliarity prior to beverage administration. Among participants assigned to the friend condition, friends reported knowing each other for an average of 2.53 years (*SD* = 2.54), spending time together 2.61 hours per week (*SD* = 1.54) throughout their acquaintance. In response to the question, "How would you describe your current level of friendship with this individual (1–9)," the mean rating was 7.27 (*SD* = 1.55). All friendship questions were completed independently and in private to reduce potential bias.

Upon entering the lab, participants' height and weight were taken (required for precise alcohol dosing). All participants were required to provide 0.00% BAC (Intoximeters Alco-Sensor IV) reading and female participants were required to take a pregnancy test (Human chorionic gonadotropin [hCG] urine test strip). Following the completion of baseline questionnaires—including measures of demographics, alcohol use history, and other assessments unrelated to the current study (for a full list, see ClinicalTrials.gov entry NCT03449095)—participants consumed their assigned study beverages (Alcohol or Control) in pairs over the course of 36 minutes. The dose of alcohol was adjusted based on each participant's estimated body water content, calculated using an updated version of the Widmark formula[99,100] that accounts for weight, height, sex, and age, and calibrated to achieve a peak BAC of approximately .08%. Participants in the alcohol condition received the study beverage in the form of a vodka-soda cocktail, whereas participants in the control condition received the volumetric equivalent of a soda beverage. Due to unanticipated compensatory reactions from placebo manipulations in prior laboratory alcohol research,[101,102] and to replicate use conditions in the real-world contexts we were seeking to understand, no deception was employed regarding the content of participants' beverages in the control condition (i.e., control participants were aware they were not consuming alcohol).

Following beverage-administration, participants were brought into separate rooms to provide BAC readings and complete self-report questionnaires, including an Eight-Item Mood Measure (8MM),[103,104] the Inclusion of Other in the Self (IOS) Scale,[105] and the Perceived Group Reinforcement Scale (PGRS)[106] (see Table 2). Upon completion of the self-report questionnaires, each dyad member was fitted with a stretchable electrode cap (Easycap, BrainVision LLC), to which 13 silver/silver-chloride electrodes were attached; these encompassed left and right prefrontal, medial frontal, medio-lateral frontal, medio-lateral central, and medio-lateral parietal locations, as well as midline central (equivalent to Cz), posterior, and occipital sites. To record eye movements and blinks, electrodes were placed on the outer canthus of each eye and the left orbital ridge. All scalp electrodes were referenced online to the left mastoid and re-referenced offline to the average of the right and the left mastoids. The continuous EEG was amplified using Sensorium amplifiers through a bandpass filter of .02–100 Hz and recorded at a sampling rate of 250 Hz.

Dyads next completed an ERP hyperscanning task while seated side-by-side (30 cm separation) in the EEG recording chamber (see Figure 1-a). A gambling task was chosen as one that elicits a strong and reliable FE[71,76,107,108] while also demonstrating sensitivity to social observation.[88] In the course of this game, participants are presented with two values (combinations of $10, $20, $30, $40, and $50) on a computer screen, each of which represents a possible win or loss amount (e.g., "$20 or $50"). The player selected one of these values by pressing a button on a handheld response device, and, following this selection, they were informed whether they won or lost the amount of money they selected (see Figure 1-b). After a practice block, dyads engaged in 4 rounds (i.e., blocks) of the game, alternating roles of player and observer (order randomly assigned), with each round consisting of 80 consecutive trials. In each block, participants were shown 32 stimuli with a value difference of 10, 24 stimuli with a difference of 20, 16 with a difference of 30, and 8 with a difference of 40. Specific pairings of values were presented 8 times in each block, with position of the numbers on the screen counterbalanced. Order of presentation of the value pairings was randomized within each block. The feedback on each trial (i.e., whether the choice was a win or a loss) was generated randomly with the constraint that, across the experiment, half the trials were losses and half wins. Feedback consisted of the chosen value presented in the center of the screen, with losses presented in red with a minus sign in front of the value and gains in green with a plus sign.

Participants were informed that the goal of the game was to maximize the amount of "money" earned as a team, with the potential to trade money earned in the game for prizes. A cooperative prize structure was chosen for this task in light of our focus on potential social-cohesive effects of alcohol. Dyads were asked to refrain from talking or moving during the course of the game, and EEG output was continuously monitored to ensure compliance. To further maximize observer engagement, participants not actively playing were instructed to keep mental track of wins and losses. Each trial began with an array of fixation crosses for 500 ms, followed by 300 ms of blank screen. Value choices were presented for 1200 ms, followed, 300 ms later, by the feedback screen for 400 ms. The next trial began 1100 ms later.

EEG processing followed established guidelines[109]. Data were digitally filtered from 0.2 to 30 Hz. To measure FEs, which are observed 200-350 ms after stimulus onset, 1000 ms epochs were extracted, from 100 ms prior to stimulus onset to 900 ms post-stimulus onset, with the 100 ms pre-stimulus period used as a baseline. Thresholds for exclusion of trials contaminated by blocking, drift, large eye movements, and excessive muscle activity were established for each participant using condition-blind visual screening. Eye blink activity was corrected.[110] Average trial loss to artifacts was 11% (range 0-58%), and all available, artifact-free trials were included in the computation of the mean amplitudes. Based on previous research, the mean amplitudes of evoked potentials to negative (loss) versus positive (gain) feedback were extracted separately for each trial and role (player and observer), averaged across four medial frontal sites (see top of Figure 2).[71,76,77]

Multi-level modeling was used to assess the impact of alcohol on FEs, accounting for the nested structure of the data, with individual gain and loss trials (Level 1) nested within participants (Level 2), who were nested within dyads (Level 3). For within amplitude level analyses, fixed effects in the models included Feedback (gain vs. loss), Beverage Condition (alcohol vs. control), and Social Context (friend vs. stranger), as well as their interactions. Random intercepts were specified at both the participant and dyad levels to account for between-subject and between-dyad variability. Importantly, ERP responses to gain and loss feedback were modeled separately within this analytic framework. FE scores—created at the level of the subject by subtracting evoked potentials for loss from gain trials—were used only in models assessing the correlation between player and observer ERP responses during simultaneous gameplay.

Data and code availability statement. All data and code required for replicating analyses can be accessed at https://osf.io/rzexg/. The analysis code developed for this study, including the multilevel models employed to assess the impact of alcohol on FEs, is also available via the OSF repository. The code is written in SAS (SAS Institute Inc., Cary, NC, USA), and detailed instructions for replicating the analyses are provided within the repository.

Results

Beverage Manipulation Check: Participants assigned to receive alcohol achieved an average BAC of .068% (SD=.019) following the group drink period, ultimately rising to a peak BAC of .076% (SD=.012) measured immediately following the hyperscanning task.

Self-Report Associations: Analyses revealed associations between player FE values and self-reports of social bonding and mood immediately prior to the gambling task. Player FEs were significantly associated with both self-other overlap[105] with the individual observing them (their co-player), b=.261, t=2.57, p=.0124, as well as negative mood measured after interacting with this individual, b=-.149, t=-2.27, p=.0264. Higher player FE values were linked with greater self-other overlap and lower negative mood. Whereas associations between *o*FEs and self-reports did not reach significance, effects tended in the opposite direction, with higher levels of social-emotional reward being associated with lower *o*FE values (see Table 2 for a full correlation matrix).

Social Effects

Player-Observer Correlations: Analyses indicated significant associations between the magnitude of a player's FE and the magnitude of the FE elicited by the individual observing that player simultaneously during the same portion of the gambling task (see Figure 2). Specifically, as the size of FEs among players increased, the size of *o*FEs also significantly increased, b=.194, t=2.20, d=0.255, p=.0312, an effect that remained significant after controlling for trial loss, b=.191, t=2.21, d=0.251, p=.0306, as well as for the total amount won/lost in usable trials,

b=.197, t=2.30, d=0.256, p=.0249. In contrast, when players' and observers' FE values were linked at the level of the participant vs. simultaneous play (i.e., when a player's FE was linked with their own FE as an observer measured later/earlier in the same session) the player-observer FE correlation emerged as non-significant, b=.132, t=1.54, d=0.027, p=.1289, as it did when observer values were shuffled across dyads, b=.050, t=.67, d= -0.076, p=.5027. Thus, in this case, (shared) setting appeared to trump person-level factors as a driver of shared variation in FEs. Finally, the player-observer FE association did not appear to be driven by similarity/selection effects within friend dyads, as the association between player and observer FEs emerged as significant selectively among strangers, b=.290, t=2.87, d=0.386, p=.0073, and did not reach significance among friends, b=.124, t=.97, d=0.162, p=.3394.

Alcohol Effects

Player FEs: In line with pre-registered planned comparisons (NCT03449095), primary models explore feedback by alcohol interactions separately within unfamiliar (stranger) dyads, with friend dyads offering a secondary point of comparison for understanding generalizability of effects across variable social contexts. For player FE values, a robust (expected) effect of feedback emerged across experimental conditions. For those assigned to complete study tasks in the company of a stranger, there was no significant interaction between alcohol condition and feedback, b=.316, t=.66, d=1.359, p=.5171, with the effect of feedback emerging as significant and strong across both alcohol, b=1.659, t=5.16, d=1.481, p<.0001, and control conditions, b=1.975, t=5.52, d=1.607, p<.0001. A similar pattern of findings was observed among participants assigned to complete the task with a friend, with no significant Alcohol by Feedback interaction, b=-.187, t=-.39, d=1.129, p=.698, and a significant effect of feedback across both alcohol, *b*=1.801, *t*=6.24, *d*= 1.481, *p*<.0001, and control, *b*=1.614, *t*=4.24, *d*= 1.607, *p*=.0002, conditions. See Figure 3 and Table 3.

Observer FEs: For FEs focused specifically in the social (i.e., observational) domain, effects emerged selectively according to participants' intoxication level and social surroundings. Specifically, for participants assigned to complete tasks with a stranger, there was a significant interaction between alcohol condition and feedback, *b*=.935, *t*=2.54, *d*= 0.642, *p*=.0165 (see Figure 4). A significant *o*FE emerged selectively among unfamiliar dyads assigned to consume no alcohol, *b*=.793, *t*=4.11, *d*=0.693, *p*=.0003, while this effect was eliminated with alcohol intoxication, *b*=-.142, *t*=-0.45, *d*=-0.107, *p*=.6549. In contrast, irrespective of alcohol group assignment, *o*FEs among participants who were already friends more closely resembled effects captured among intoxicated strangers. Within friend dyads, no significant interaction between alcohol condition and feedback emerged, *b*=.216, *t*=.39, *d*=0.007, *p*=.6991—*o*FEs were non-significant within both control, *b*=.011, *t*=.03, *d*=0.006, *p*=.9801, and alcohol, *b*=.227, *t*=.71, *d*=0.167, *p*=.485, conditions. See Figures 3 and 4, and Table 3.

Exploratory Analyses

Although our primary analyses examined gain and loss trials together to assess FE responses, analyzing them separately allows detection of asymmetrical effects—such as selective attenuation of reward responses (e.g., RewP[111]) or amplification of loss signals (e.g., FRN[112])—that may be masked in a difference score. Therefore, we conducted exploratory analyses examining the main effect of alcohol separately on gain and loss trials. Results indicated that alcohol did not produce statistically significant main effects on either gain (*b*=1.28, *t*=1.83, *d*=0.162, *p*=.072) or loss (*b*=1.07, *t*=1.64, *d*=0.145, *p*=.107) ERP amplitudes. Similarly, social context showed no significant effects on gain (*b*=-0.32, *t*=-0.44, *d*=0.039, *p*=.660) or loss (*b*=-

0.48, t=-0.71, d=0.063, p=.478) trials when modeled independently. These findings suggest that the observed alcohol- and context-related effects are most evident in the contrast between gain and loss responses, i.e., the FE, rather than in absolute amplitude changes within either condition.

Discussion

By employing experimental alcohol-administration methods and an EEG hyperscanning paradigm, the present study sheds light on the interconnectedness of brains in social context. The study strategically focused on a class of event-related brain potentials—performance monitoring ERPs, or feedback effects (FEs)—which have been linked to reward processing and reinforcement learning. These responses have been linked to phasic shifts in mesencephalic dopamine signals in a brain network involved in reinforcement learning, observed when outcomes deviate from expectations, whether favorably or unfavorably.[71] We explored the impact of alcohol on performance monitoring processes, both among those actively engaging in tasks and among those observing them. Replicating prior work,[49,49,88,90] we observed that FEs are shaped by social and emotional processes, with positive correlations between the size of player FEs, self-other overlap, and reduced negative mood. Novel to this work, we discovered a significant in-the-moment correlation in the magnitude of FEs among players and observers, offering support for core social dimensions of human cognition. Critically, findings further revealed alcohol effects that emerged specifically in the social domain, with alcohol intoxication significantly reducing the magnitude of FEs among observers paired with a stranger. In contrast, alcohol's impact on FEs was non-significant when participants observed an individual who was already a friend, as well as when participants were actively engaged in playing, pointing to unique capabilities for alcohol in blunting social-evaluative processes in unfamiliar social settings. Overall, results of this study not only shed light on how alcohol might interface with neural processes linked with performance evaluation in social context but appear to further bolster the view of the brain as an organ steeped in not only the *intra*- but also the *inter*-personal domain.

One potential mechanism underlying this “social buffering” effect is alcohol’s modulation of the neural circuits that support social evaluation. Specifically, FEs are thought to originate primarily from the medial prefrontal cortex (mPFC), with strong contributions from the anterior cingulate cortex (ACC).[71,76] These regions form part of a broader performance monitoring network that tracks action outcomes, signaling when adjustments are needed following errors or unexpected feedback. Importantly, in social contexts, this same network plays a central role in social evaluative processing, with the ACC particularly implicated in detecting, monitoring, and responding to social conflict and feedback.[113,114] Increased ACC activation has been associated with heightened sensitivity to social rejection, negative evaluation, and the perceived need to regulate one’s behavior under social scrutiny.[113,115] In interactions with strangers—where social uncertainty is high—this evaluative network is likely to become more active, increasing vigilance to and monitoring of not only one's own behavior but the actions of others. Alcohol may buffer this response by dampening activity within the ACC and related prefrontal regions, reducing the salience of negative cues in social situations and decreasing the cognitive demands associated with social vigilance. This dampening could, in turn, lead to observable reductions in ERP amplitudes, including both FEs and *o*FEs, as observed in our study, particularly during performance monitoring in socially evaluative situations involving strangers.

The differential effects of alcohol in stranger versus friend interactions observed in our study can be understood within the ramework of social-cognitive theories[39,116] governing interpersonal vigilance. Interactions with strangers are typically marked by heightened social uncertainty and an increased need to monitor social cues, as individuals work to assess the intentions, reliability, and trustworthiness of unfamiliar others.[117,118] This increased vigilance is adaptive, serving to protect against potential social threats and to guide decisions about whether to invest in new social relationships. In contrast, interactions with friends involve established trust and familiarity,[119,120] reducing the cognitive demands of social monitoring. In these familiar contexts, individuals can relax evaluative processes, confident that their behaviors are less likely to be negatively judged or socially penalized. Within this framework, alcohol's social buffering effects may be most pronounced when evaluative demands are highest—such as in interactions with strangers—by dampening the neural systems that support social vigilance (e.g., the ACC and mPFC). When interacting with friends, however, the need for such vigilance is already low, leaving less opportunity for alcohol to further reduce evaluative processing.

Several prior studies have also found that measures of empathy or self-other overlap can influence *o*FEs, with larger effects in more empathetic individuals and in dyadic contexts with higher levels of perceived closeness.[49,86,121] However, it is important to note that these studies employed task situations in which observer and player outcomes were *independent*. Given that *o*FEs have been shown to reflect an egocentric perspective on outcomes,[47,89,90] our results suggest that, in the absence of task demands to do so, people's willingness to voluntarily "take on" others' actions may be enhanced by empathy or self-other overlap. Indeed, Ma et al.[86] found that the increased *o*FEs for friends compared to strangers only held if the observer was never actively involved in the game. Results in the present study then highlight important variability in social appraisals across relationship types and contexts, as well as a potential role for alcohol in moderating these appraisals. Notably, in a cooperative context, we found a different pattern, in which *o*FEs were present in stranger dyads but diminished (statistically not attested) in friend dyads. Other studies have also found *o*FEs in dyads made up of strangers when, as here, players' performance matters for the observer.[50,78,88] Moreover, Yu et al.[122] manipulated social closeness among strangers by establishing an "in-group" (a partner in a previous task) and an "out-group" (a previous competitor) and found larger *o*FEs for out-group than in-group members. Thus, *o*FE magnitudes can also signal the observer's level of vigilance toward players' behavior, elicited by cooperative task demands and/or social appraisal. In a cooperative task, friends seem more likely to reduce vigilance – to "trust" their partners to perform the task in a manner that will benefit the dyad and therefore to divert resources away from performance monitoring.[91] In contrast, tasks that create interdependencies among strangers may give rise to a state of heightened vigilance for observers. This state of alertness assists in navigating situations featuring uncertainty surrounding outcomes with potential implications for the self, increasing attentiveness and so potentially impacting learning.[78]

We did not find an effect of alcohol on player FEs, which aligns with some prior research,[123] although not all, as suggested by our meta-analysis.[96] Of note, previous studies have focused on alcohol's effects on ERPs within solitary settings. Alcohol's impact on attentional and performance monitoring processes has been shown to vary across task conditions, with alcohol often failing to yield effects in situations featuring highly salient stressful stimuli and/or singular task demands.[38] One possibility is that the social context and interdependent nature of outcomes in our task served to "up the ante," inducing a myopic focus on the task at hand—an attentional state over which alcohol typically exerts muted effects.[38,124,125] This underscores the necessity for future research to integrate the social dimension when examining alcohol's neurocognitive effects, as social factors may modulate the extent to which alcohol affects performance monitoring processes.

Although previous studies have independently captured FEs separately among both players and observers,[122,126–129] our current study, which also leverages a notably large sample, is (to the best of our knowledge) the first to show that there is synchrony in FEs between players and observers within the same task context. This finding has methodological as well as theoretical implications, as it presents a promising avenue for exploring the interconnectedness of brains within social contexts, through the use of hyperscanning methods in tandem with well-established EEG paradigms. Typically, hyperscanning paradigms have measured correlations (synchrony) between individuals in overall patterns of brain activity across time periods of minutes or longer, revealing the impact of factors like joint attention for learning and interpersonal evaluation.[43,45,57,130] Nevertheless, as with any methodology, concerns have been voiced about hyperscanning paradigms, particularly pertaining to the complexities of interpreting these large-scale inter-brain metrics while also considering environmental and behavioral factors.[53,130,131] In light of these considerations, our study instead combined hyperscanning with a well-studied ERP paradigm, facilitating in-vivo social interaction while simultaneously controlling for crucial aspects of the stimulus environment. Extracting ERPs while hyperscanning provides discernible individual brain responses linked to specific cognitive and neural functions, while still affording opportunities to capture synchronized brain activity among multiple individuals, thereby deepening our insight into the interplay between social contexts and the impact of alcohol on modulating social brain functioning. In this case, supplemental analyses highlighted the strength of situational (vs. individual) factors for understanding player-observer

FE correlations: Although the FE of an individual engaged in playing the gambling task was significantly linked to the *o*FE of the individual simultaneously observing them, the magnitude of a given player's FE was un-linked with the magnitude of *their own o*FE as captured later in the experiment. Moreover, these situational effects persisted even with control for task outcomes (i.e., amount won/lost), pointing to an important social dimension underlying the effect pattern.

Indeed, we observed that player FE magnitudes are positively related to self-other overlap. Although the literature contains a limited number of studies with adequate power for between-subject analyses, a relatively consistent pattern across studies is the finding that performance monitoring effects can be enhanced by social motivations. For example, players' responses to errors (Error Related Negativities) have been found to be larger for people who score higher on measures of empathy.[132,133] In our cooperative gambling task, where players' choices mattered for their co-present observers, we found that player FEs were larger when they felt more connected to their partner and thus presumably were more motivated to make choices that benefitted the dyad. The further correlation between player FEs and reduced negative mood resonates congruently with previous literature highlighting the link between diminished FE values and negative affective states, as observed within contexts including depression,[134] although when modeled together it appeared that social connection explains more variance in FE size than does emotional state. Future studies could consider examining other factors such as trait empathy, mood, and anxiety in adequately powered samples to further explore these preliminary results.

Several limitations of the present study warrant consideration. First, although our sample included substantial racial and ethnic diversity—addressing a significant gap in alcohol research—it included a relatively high proportion of demographic groups among whom subpopulations have historically demonstrated low levels of drinking (e.g., Asian participants). This diversity represents a strength, as it extends the generalizability of alcohol research beyond the predominantly White samples that have historically characterized the field.[135] However, cultural factors are known to influence drinking patterns, social behaviors, and sensitivity to alcohol's effects,[136,137] and these differences may also extend to performance-monitoring processes examined in the study. For instance, certain Asian cultural contexts (e.g., those influenced by Confusian heritage) tend to emphasize interpersonal harmony and concern for others' evaluations and, as a result, individuals from these backgrounds may experience heightened self-monitoring in unfamiliar social situations, where maintaining face and avoiding social errors are prioritized.[138,139] Such effects may differ from those observed in Western cultural contexts, where direct communication and individual assertiveness may be more normative.[140,141] However, to our knowledge, whether cultural norms interact with alcohol and social context to influence neural processing has not yet been directly tested. Future research should explore whether alcohol's social and neural effects vary across racial/cultural groups with differing drinking norms and practices, ideally in even larger and more demographically diverse samples. Second, one design consideration that may have influenced the findings was the instruction for observers to mentally track wins and losses during gameplay. This instruction was intended to ensure that observers remained attentive to task outcomes. However, this requirement may have introduced a mild cognitive load that could have detracted from participants' full emotional engagement with the task, particularly across a high number of trials. While we did not observe any clear attenuation of feedback-related ERP components indicative of disengagement, future studies might consider alternative strategies to sustain observer attention without imposing additional cognitive demands. Third, while the decision not to use deception in the control beverage condition was intentional and aligned with real-world drinking contexts, it is important to acknowledge that this approach may have introduced expectancy effects, potentially influencing participants' social evaluations and neural responses. Future studies might consider incorporating a placebo condition to assess whether the current findings replicate under blinded conditions.

Taken together, the results highlight the critical interplay of alcohol and social settings on performance monitoring processes. Social cohesion tends to increase performance monitoring for players, and we showed here for the first time that, at least in cooperative tasks, FEs between players and observers become synchronized. However, alcohol dampened the *o*FEs that were otherwise elicited in stranger dyads, pointing to reduced vigilance and possibly increased cohesion and trust. This interaction of alcohol with social dynamics suggests implications for societal functions and tendencies toward addiction.[33] Considered together with research pointing to a role for hazardous consumption in contexts featuring social novelty, our research indicates that alcohol may release us from a state of hypervigilant social evaluation in the early stages of relationship formation, so potentially releasing resources for shared pleasures.

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Author Contributions

Dahyeon Kang played lead role in conceptualization, investigation, project administration, visualization, writing of original draft and writing of review and editing and equal role in data curation, formal analysis, funding acquisition, methodology, resources and validation. Catharine E. Fairbairn played lead role in supervision and writing of review and editing and equal role in conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, validation and writing of original draft. Jiaxu Han played supporting role in data curation and equal role in formal analysis. Kara D. Federmeier played lead role in supervision, supporting role in formal analysis and equal role in conceptualization, funding acquisition, investigation, methodology, resources, validation, writing of original draft and writing of review and editing. All authors reviewed and approved the final version of the manuscript.

Figures, with Titles and Legends

Figure 1. Experimental set-up and ERP task design of the hyperscanning procedures.

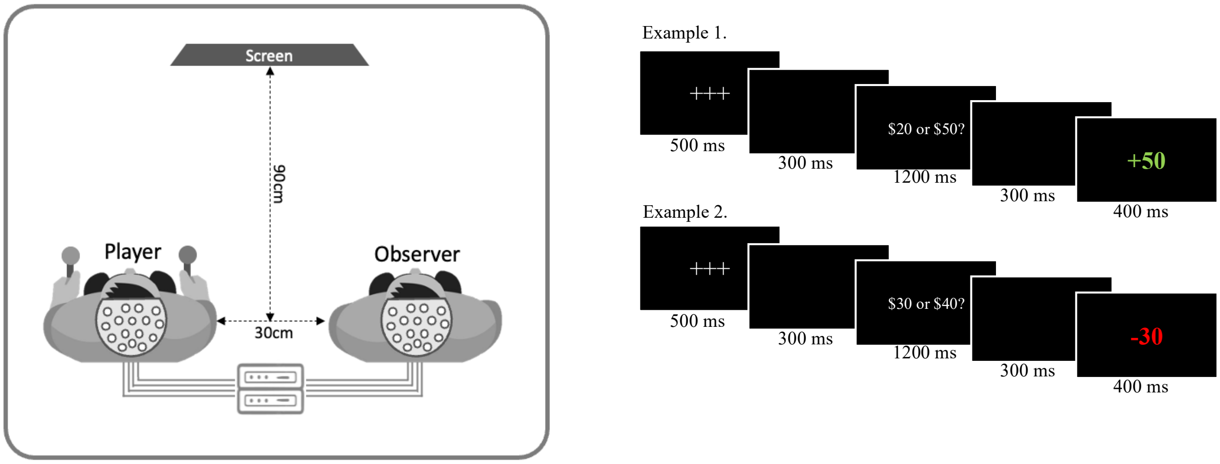
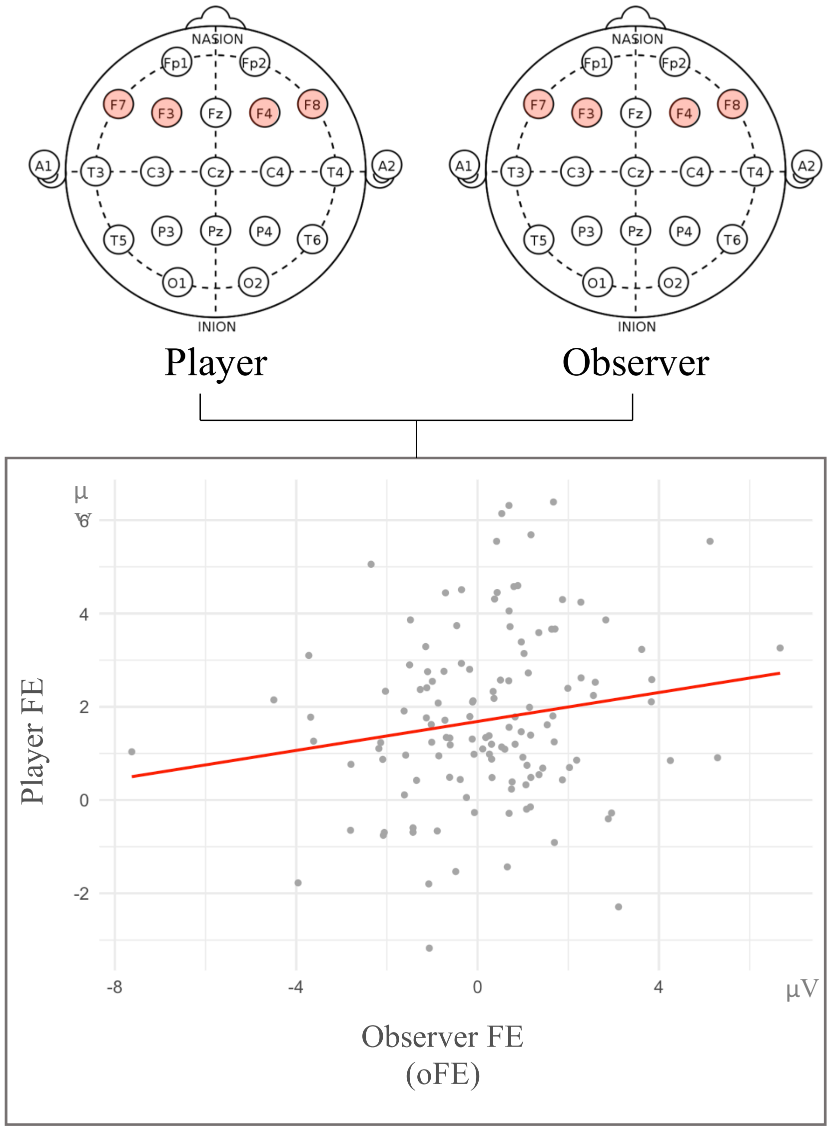


Figure 1-a (left). Dyads completed the ERP task while seated side-by-side in the EEG recording chamber. The player made monetary selections using a button press on a handheld response device.

Figure 1-b (right). Experimental stimuli and task design. In the course of this game, participants are presented with two values (combinations of $10, $20, $30, $40, and $50) on a computer screen, each of which represents a possible win or loss amount. Participants are required to select one of these values, and, following this selection, they are informed whether they won or lost the amount of money they selected.

Figure 2. Player-Observer Feedback Effect (FE) Correlations



Top: Red dots indicate the scalp positions of the four electrodes used in the current FE analyses for both players and observers
Bottom: Scatter plot showing significant associations between the magnitude of a player's FE and the corresponding FE magnitude elicited in the observer during the same phase of the gambling task.

Figure 3. Alcohol's Impact on player and observer FEs.

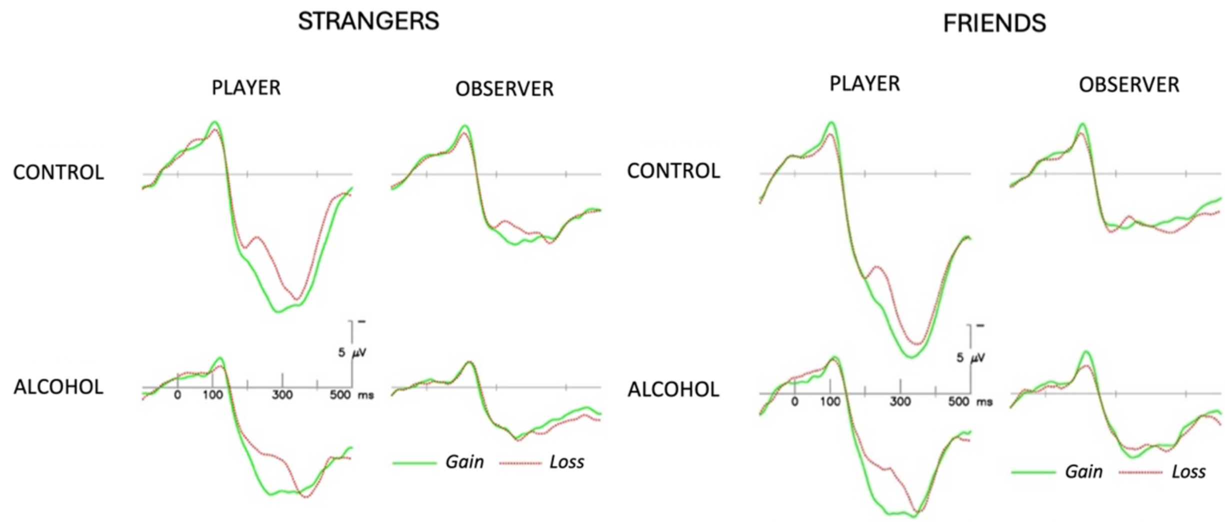


Figure 3-a. (top): Grand-averaged EEG responses recorded across medial and lateral frontal electode sites (F3, F4, F7, F8; see Figure 2), separately plotted for players and observers across all experimental conditions.

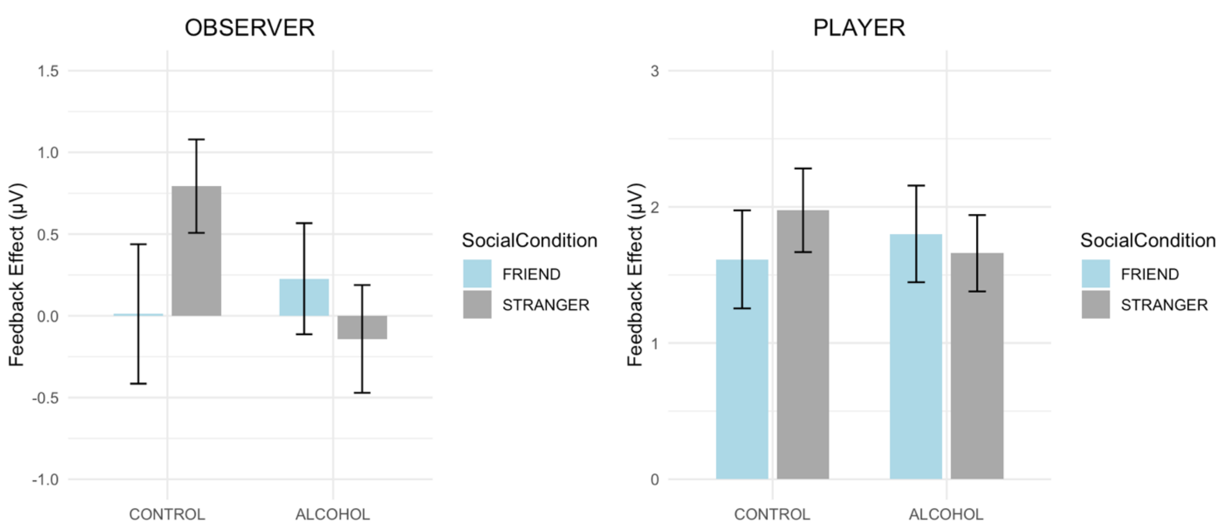
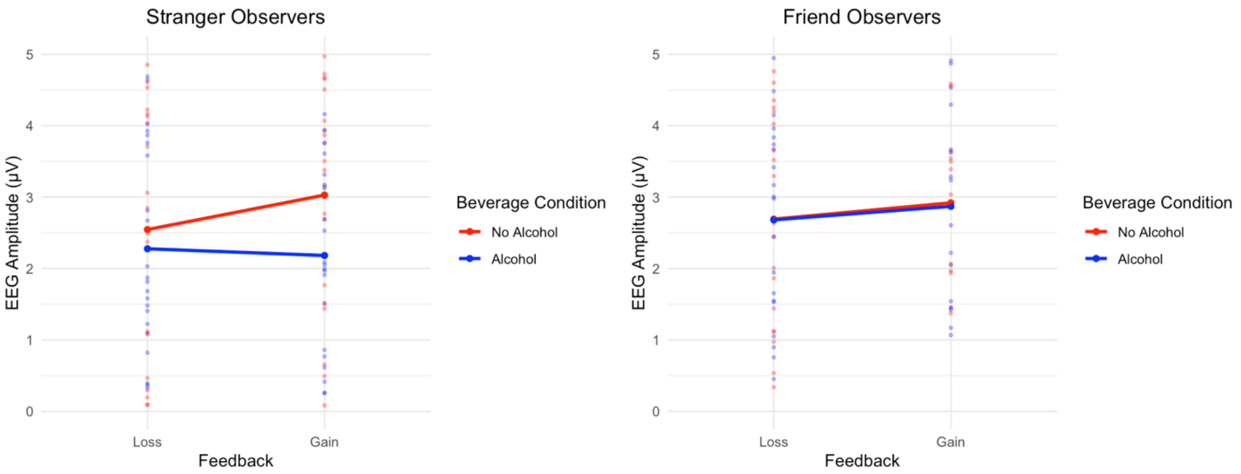


Figure 3-a. (bottom): Bar plots visualizing the sizes of FEs for each condition. Error bars represent the standard error (SE) of the mean.

Figure 4. Interaction between Beverage Condition and Feedback on ERP Amplitudes among Observers



Left: Among participants assigned to complete tasks with a stranger, there was a significant interaction between alcohol condition and feedback, b=.935, t=2.54, d= 0.642, p=.0165. A significant *o*FE emerged selectively among unfamiliar dyads assigned to consume no alcohol, b=.793, t=4.11, d=0.693, p=.0003, while this effect was eliminated with alcohol intoxication, b=-.142, t=-0.45, d=-0.107, p=.6549.
Right: Among friend dyads, no significant interaction between alcohol condition and feedback emerged, b=.216, t=.39, d=0.007, p=.6991—*o*FEs were non-significant within both control, b=.011, t=.03, d=0.006, p=.9801, and alcohol, b=.227, t=.71, d=0.167, p=.485, conditions.

Tables with Titles and Legends

Table 1. Descriptive Statistics of the Participants

Variable	Descriptive Statistics	
	M (SD)	
Age	23.02 (2.11)	
Gender	**n**	**Percentage**
Female	64	50%
Male	64	50%
Race/Ethnicity	**n**	**Percentage**
White	69	53.91%
Black	4	3.13%
Asian	52	40.63%
Native Hawaiian/Other Pacidic Islander	2	1.56%
More than one race	2	1.56%
Hispanic/Latino	34	26.56%
Alcohol use (past 30 days)	**M (SD)**	
Drinking Days	7.48 (4.71)	
Number of Drinks per Occasion	3.64 (1.75)	
Other substance use (past 30 days)	**n**	**Percentage**
Hallucinogen (e.g., psilocybin, LSD)	2	0.02%
Heroin	0	0.01%
Opioids	0	0.00%
Benzodiazepines	0	0.00%
Other Depressants/Sedatives	0	0.00%
Stimulants	1	0.01%

Table 2. Full Correlation Matrix on the Associations Between FEs and Self-Report Measures

	PGRS	8MM—Positive	8MM—Negative	IOS	Player FE	Observer FE
Social Bonding (PGRS[106])	1	.401**	-.227**	.529**	-0.091	-0.045
Positive Mood (8MM°)	.401**	1	-.264**	.258**	-0.149	0.066
Negative Mood (8MM°)	-.227**	-.264**	1	-.204*	-0.012	-.192*
Self-Other Overlap (IOS[105])	.529**	.258**	-.204*	1	-0.012	.192*
Player FE	-0.091	-0.149	-0.012	-0.137	1	0.122
Observer FE	-0.045	0.066	-.192*	.192*	0.122°°	1

** $p < .001$

* $p < .05$

° The 8MM assesses four negative mood states (annoyed, sad, irritated, bored) and four positive mood states (cheerful, upbeat, happy, content), encompassing all quadrants of Russell's affective circumplex.[142]

°° Significant associations were found between a player's FE and the FE of an observing individual during simultaneous play, but the correlation became non-significant when linking a player's FE with their own FE as an observer, emphasizing the role of shared settings over individual factors in shared FE variation (see ***Social Effects***: *Player-Observer Correlations*).

Table 3. Descriptive Statistics of FEs (mV) across Conditions

Conditions			Mean	sd
Strangers	Control	Observer FE	0.79	1.62
		Player FE	1.97	1.74
	Alcohol	Observer FE	-0.14	1.87
		Player FE	1.66	1.58
Friends	Control	Observer FE	0.01	2.41
		Player FE	1.61	2.04
	Alcohol	Observer FE	0.23	1.92
		Player FE	1.80	2.01

References

1. Hamill, P. *From A Drinking Life: A Memoir*. (Back Bay Books, 1994).
2. Hemingway, E. *For Whom the Bell Tolls*. (Collier Books, New York, 1987).
3. Aronson, E. *The Social Animal*. (Worth Publishers, New York, 2012).
4. Dawkins, R. *The Extended Phenotype: The Gene as the Unit of Selection*. (Freeman, Oxford [Oxfordshire] ; San Francisco, 1982).
5. Gulati, R. Social structure and alliance formation patterns: A longitudinal analysis. *Adm. Sci. Q.* **40**, 619 (1995).
6. *Social Structures: A Network Approach*. (Cambridge University Press, Cambridge [Cambridgeshire] ; New York, 1988).
7. Lin, N. *Social Capital: A Theory of Social Structure and Action*. (Cambridge Univ. Pr, Cambridge, 2007).
8. Dunbar, R. I. M. The social brain hypothesis. *Evol. Anthropol. Issues News Rev.* **6**, 178–190 (1998).
9. Greene, J. D. *Moral Tribes: Emotion, Reason, and the Gap between Us and Them*. (Atlantic books, London, 2014).
10. Morrison, T. *The Origin of Others*. (Harvard University Press, 2017). doi:10.4159/9780674982628.
11. Beck, U. *Risk Society: Towards a New Modernity*. (Sage Publications, London ; Newbury Park, Calif, 1992).
12. Taleb, N. N. *The Black Swan: The Impact of the Highly Improbable*. (Random House, New York, 2007).
13. LeDoux, J. E. & Sorrentino, C. da S. *The Deep History of Ourselves: The Four-Billion-Year Story of How We Got Conscious Brains*. (Penguin Books, London, 2020).
14. Ramachandran, V. S. *The Tell-Tale Brain: A Neuroscientist's Quest for What Makes Us Human*. (W.W. Norton, New York, 2011).
15. Baumeister, R. F. *The Cultural Animal: Human Nature, Meaning, and Social Life*. (Oxford University Press, Oxford, UK ; New York, 2005).

16. Goleman, D. *Social Intelligence: The New Science of Human Relationships*. (Bantam Books, New York, 2007).

17. Wasserman, S. & Faust, K. *Social Network Analysis: Methods and Applications*. (Cambridge University Press, Cambridge ; New York, 1994).

18. *Alcohol and Humans: A Long and Social Affair*. (Oxford University Press, Oxford, United Kingdom ; New York, NY, 2020).

19. Steele, C. M. & Southwick, L. Alcohol and social behavior I: The psychology of drunken excess. *J. Pers. Soc. Psychol.* **48**, 18–34 (1985).

20. McGovern, P. E. *Ancient Wine: The Search for the Origins of Viniculture*. (Princeton University Press, Princeton, 2013). doi:10.1515/9781400849536.

21. Standage, T. *A History of the World in 6 Glasses*. (Bloomsbury, New York, 2006).

22. Slingerland, E. *Drunk: How We Sipped, Danced, and Stumbled Our Way to Civilization*. (Little, Brown Spark, New York, 2021).

23. Aan Het Rot, M., Russell, J. J., Moskowitz, D. S. & Young, S. N. Alcohol in a social context: Findings from event-contingent recording studies of everyday social interactions. *Alcohol. Clin. Exp. Res.* **32**, 459–471 (2008).

24. Doty, P. & de Wit, H. Effect of setting on the reinforcing and subjective effects of ethanol in social drinkers. *Psychopharmacology (Berl.)* **118**, 19–27 (1995).

25. Kirkpatrick, M. G. & de Wit, H. In the company of others: Social factors alter acute alcohol effects. *Psychopharmacology (Berl.)* **230**, 215–226 (2013).

26. Pliner, P. & Cappell, H. Modification of affective consequences of alcohol: A comparison of social and solitary drinking. *J. Abnorm. Psychol.* **83**, 418–425 (1974).

27. Cooper, M. L. Motivations for alcohol use among adolescents: Development and validation of a four-factor model. *Psychol. Assess.* **6**, 117–128 (1994).

28. Brown, S. A. Context of drinking and reinforcement from alcohol: Alcoholic patterns. *Addict. Behav.* **10**, 191–195 (1985).

29. Casswell, S. & Zhang, J. F. Access to alcohol from licensed premises during adolescence: A longitudinal study. *Addiction* **92**, 737–745 (1997).

30. Fairbairn, C. E. *et al.* A multimodal investigation of contextual effects on alcohol's emotional rewards. *J. Abnorm. Psychol.* **127**, 359–373 (2018).

31. Senchak, M., Leonard, K. E. & Greene, B. W. Alcohol use among college students as a function of their typical social drinking context. *Psychol. Addict. Behav.* **12**, 62–70 (1998).

32. Shih, R. A. *et al.* Associations between neighborhood alcohol availability and young adolescent alcohol use. *Psychol. Addict. Behav.* **29**, 950–959 (2015).

33. Nutt, D. J., King, L. A. & Phillips, L. D. Drug harms in the UK: a multicriteria decision analysis. *The Lancet* **376**, 1558–1565 (2010).

34. Bjork, J. M. & Gilman, J. M. The effects of acute alcohol administration on the human brain: insights from neuroimaging. *Neuropharmacology* **84**, 101–110 (2014).

35. Rickenbacher, E., Greve, D. N., Azma, S., Pfeuffer, J. & Marinkovic, K. Effects of alcohol intoxication and gender on cerebral perfusion: an arterial spin labeling study. *Alcohol* **45**, 725–737 (2011).

36. Strang, N. M. *et al.* Dose-dependent effects of intravenous alcohol administration on cerebral blood flow in young adults. *Psychopharmacology (Berl.)* **232**, 733–744 (2015).

37. Marxen, M. *et al.* Acute effects of alcohol on brain perfusion monitored with arterial spin labeling magnetic resonance imaging in young adults. *J. Cereb. Blood Flow Metab.* **34**, 472–479 (2014).

38. Steele, C. M. & Josephs, R. A. Alcohol myopia: Its prized and dangerous effects. *Am. Psychol.* **45**, 921–933 (1990).

39. Fairbairn, C. E. & Sayette, M. A. A social-attributional analysis of alcohol response. *Psychol. Bull.* **140**, 1361–1382 (2014).

40. Curtin, J. J. & Fairchild, B. A. Alcohol and cognitive control: Implications for regulation of behavior during response conflict. *J. Abnorm. Psychol.* **112**, 424–436 (2003).

41. Sayette, M. A. The effects of alcohol on emotion in social drinkers. *Behav. Res. Ther.* **88**, 76–89 (2017).

42. Fairbairn, C. E. & Kang, D. Social Drinking and Addiction: A Social-Cognitive Model for Understanding Alcohol Use Disorder Risk. *Curr. Dir. Psychol. Sci.* 09637214251318272 (2025) doi:10.1177/09637214251318272.

43. Dikker, S. *et al.* Crowdsourcing neuroscience: inter-brain coupling during face-to-face interactions outside the laboratory. *NeuroImage* **227**, 117436 (2021).

44. Hari, R., Himberg, T., Nummenmaa, L., Hämäläinen, M. & Parkkonen, L. Synchrony of brains and bodies during implicit interpersonal interaction. *Trends Cogn. Sci.* **17**, 105–106 (2013).

45. Hasson, U., Nir, Y., Levy, I., Fuhrmann, G. & Malach, R. Intersubject synchronization of cortical activity during natural vision. *science* **303**, 1634–1640 (2004).

46. Montague, P. R. *et al.* Hyperscanning: simultaneous fMRI during linked social interactions. *NeuroImage* **16**, 1159–1164 (2002).

47. van Schie, H. T., Mars, R. B., Coles, M. G. H. & Bekkering, H. Modulation of activity in medial frontal and motor cortices during error observation. *Nat. Neurosci.* **7**, 549–554 (2004).

48. Zhang, D., Lin, Y., Jing, Y., Feng, C. & Gu, R. The dynamics of belief updating in human cooperation: findings from inter-brain ERP hyperscanning. *NeuroImage* **198**, 1–12 (2019).

49. Jin, J., Wang, A., Liu, J., Pan, J. & Lyu, D. How does monetary loss empathy modulate generosity in economic sharing behavior? An ERPs study. *Neuropsychologia* **141**, 107407 (2020).

50. Yu, R. & Zhou, X. Brain responses to outcomes of one's own and other's performance in a gambling task. *NeuroReport* **17**, 1747–1751 (2006).

51. Barker, T. V., Troller-Renfree, S., Pine, D. S. & Fox, N. A. Individual differences in social anxiety affect the salience of errors in social contexts. *Cogn. Affect. Behav. Neurosci.* **15**, 723–735 (2015).

52. Verbeke, W. J., Pozharliev, R., Van Strien, J. W., Belschak, F. & Bagozzi, R. P. "I am resting but rest less well with you." The moderating effect of anxious attachment style on alpha power during EEG resting state in a social context. *Front. Hum. Neurosci.* **8**, 486 (2014).

53. Holroyd, C. B. Interbrain synchrony: on wavy ground. *Trends Neurosci.* (2022).

54. Balconi, M. & Vanutelli, M. E. Interbrains cooperation: Hyperscanning and self-perception in joint actions. *J. Clin. Exp. Neuropsychol.* **39**, 607–620 (2017).

55. Tugin, S., Gorin, A., Kanunikov, I. & Shestakova, A. Hyperscanning of social attunement: An frn study. *Journal of Higher School of Economic Psychology* 48–63 (2015).

56. Dumas, G., Nadel, J., Soussignan, R., Martinerie, J. & Garnero, L. Inter-brain synchronization during social interaction. *PloS One* **5**, e12166 (2010).

57. Kawasaki, M., Yamada, Y., Ushiku, Y., Miyauchi, E. & Yamaguchi, Y. Inter-brain synchronization during coordination of speech rhythm in human-to-human social interaction. *Sci. Rep.* **3**, 1692 (2013).

58. Babiloni, F. *et al.* Cortical Activity and Connectivity of Human Brain during the Prisoner's Dilemma: an EEG Hyperscanning Study. in *2007 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society* 4953–4956 (IEEE, Lyon, France, 2007). doi:10.1109/IEMBS.2007.4353452.

59. Jahng, J., Kralik, J. D., Hwang, D.-U. & Jeong, J. Neural dynamics of two players when using nonverbal cues to gauge intentions to cooperate during the Prisoner's Dilemma Game. *NeuroImage* **157**, 263–274 (2017).

60. Dikker, S. *et al.* Brain-to-brain synchrony tracks real-world dynamic group interactions in the classroom. *Curr. Biol.* **27**, 1375–1380 (2017).

61. Djalovski, A., Dumas, G., Kinreich, S. & Feldman, R. Human attachments shape interbrain synchrony toward efficient performance of social goals. *Neuroimage* **226**, 117600 (2021).

62. Hasson, U., Ghazanfar, A. A., Galantucci, B., Garrod, S. & Keysers, C. Brain-to-brain coupling: a mechanism for creating and sharing a social world. *Trends Cogn. Sci.* **16**, 114–121 (2012).

63. Fabiani, M., Gratton, G. & Federmeier, K. D. Event-related brain potentials: Methods, theory, and applications. in *Handbook of Psychophysiology* (eds Cacioppo, J. T., Tassinary, L. & Berntson, G.) 85–119 (Cambridge University Press, Cambridge, 2007).

64. Münte, T. F., Urbach, T. P., Düzel, E. & Kutas, M. Event-related brain potentials in the study of human cognition and neuropsychology. in *Handbook of Neuropsychology* (eds Boller, F., Grafman, J. & Rizzolatti, G.) vol. 1 139–235 (Elsevier, Amsterdam, 2000).

65. Kinreich, S., Djalovski, A., Kraus, L., Louzoun, Y. & Feldman, R. Brain-to-brain synchrony during naturalistic social interactions. *Sci. Rep.* **7**, 1–12 (2017).

66. Czeszumski, A. *et al.* Hyperscanning: A Valid Method to Study Neural Inter-brain Underpinnings of Social Interaction. *Front. Hum. Neurosci.* **14**, 39 (2020).

67. Kayhan, E. *et al.* Interpersonal neural synchrony when predicting others' actions during a game of rock-paper-scissors. *Sci. Rep.* **12**, 12967 (2022).

68. Nam, C. S., Choo, S., Huang, J. & Park, J. Brain-to-brain neural synchrony during social interactions: A systematic review on hyperscanning studies. *Appl. Sci.* **10**, 6669 (2020).

69. Falkenstein, M., Hohnsbein, J., Hoormann, J. & Blanke, L. Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalogr. Clin. Neurophysiol.* **78**, 447–455 (1991).

70. Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E. & Donchin, E. A Neural System for Error Detection and Compensation. *Psychol. Sci.* **4**, 385–390 (1993).

71. Holroyd, C. B. & Coles, M. G. H. The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychol. Rev.* **109**, 679–709 (2002).

72. Hajcak, G., Moser, J. S., Yeung, N. & Simons, R. F. On the ERN and the significance of errors. *Psychophysiology* **42**, 151–160 (2005).

73. Holroyd, C. B. & Krigolson, O. E. Reward prediction error signals associated with a modified time estimation task. *Psychophysiology* **44**, 913–917 (2007).

74. Proudfit, G. H. The reward positivity: From basic research on reward to a biomarker for depression: The reward positivity. *Psychophysiology* **52**, 449–459 (2015).

75. Krigolson, O. E. Event-related brain potentials and the study of reward processing: Methodological considerations. *Int. J. Psychophysiol.* **132**, 175–183 (2018).

76. Gehring, W. J. & Willoughby, A. R. The medial frontal cortex and the rapid processing of monetary gains and losses. *Science* **295**, 2279–2282 (2002).

77. Holroyd, C. B. *et al.* Dorsal anterior cingulate cortex shows fMRI response to internal and external error signals. *Nat. Neurosci.* **7**, 497–498 (2004).

78. Marco-Pallarés, J., Krämer, U. M., Strehl, S., Schröder, A. & Münte, T. F. When decisions of others matter to me: an electrophysiological analysis. *BMC Neurosci.* **11**, 86 (2010).

79. Balconi, M. & Vanutelli, M. E. Cooperation and Competition with Hyperscanning Methods: Review and Future Application to Emotion Domain. *Front. Comput. Neurosci.* **11**, 86 (2017).

80. Fiske, S. T. *Social Beings: Core Motives in Social Psychology*. (John Wiley & Sons, Inc, Hoboken, NJ, 2019).

81. *Heuristics and Biases: The Psychology of Intuitive Judgment*. (Cambridge University Press, Cambridge, U.K. ; New York, 2002).

82. Tversky, A. & Kahneman, D. Judgment under uncertainty: Heuristics and biases: Biases in judgments reveal some heuristics of thinking under uncertainty. *Science* **185**, 1124–1131 (1974).

83. Cavanagh, J. F. & Shackman, A. J. Frontal midline theta reflects anxiety and cognitive control: Meta-analytic evidence. *J. Physiol.-Paris* **109**, 3–15 (2015).

84. Tian, T. *et al.* Modulation of the brain activity in outcome evaluation by the presence of an audience: An electrophysiological investigation. *Brain Res.* **1615**, 139–147 (2015).

85. Czeszumski, A., Ehinger, B. V., Wahn, B. & König, P. The Social Situation Affects How We Process Feedback About Our Actions. *Front. Psychol.* **10**, 361 (2019).

86. Ma, Q. *et al.* Empathic responses to others' gains and losses: An electrophysiological investigation. *NeuroImage* **54**, 2472–2480 (2011).

87. Koban, L., Pourtois, G., Bediou, B. & Vuilleumier, P. Effects of social context and predictive relevance on action outcome monitoring. *Cogn. Affect. Behav. Neurosci.* **12**, 460–478 (2012).

88. Koban, L., Pourtois, G., Vocat, R. & Vuilleumier, P. When your errors make me lose or win: Event-related potentials to observed errors of cooperators and competitors. *Soc. Neurosci.* **5**, 360–374 (2010).

89. Itagaki, S. & Katayama, J. Self-relevant criteria determine the evaluation of outcomes induced by others. *NeuroReport* **19**, 383–387 (2008).

90. Koban, L. & Pourtois, G. Brain systems underlying the affective and social monitoring of actions: An integrative review. *Neurosci. Biobehav. Rev.* **46**, 71–84 (2014).

91. Carp, J., Halenar, M. J., Quandt, L. C., Sklar, A. & Compton, R. J. Perceived similarity and neural mirroring: Evidence from vicarious error processing. *Soc. Neurosci.* **4**, 85–96 (2009).

92. Axelrod, R. M. *The Evolution of Cooperation*. (Basic Books, New York, 2006).

93. Bradford, D. E., Shapiro, B. L. & Curtin, J. J. How bad could it be? Alcohol dampens stress responses to threat of uncertain intensity. *Psychol. Sci.* **24**, 2541–2549 (2013).

94. Fiske, S. T. *Social Beings: A Core Motives Approach to Social-Psychology*. (Wiley, Hoboken, NJ, 2004).

95. Hefner, K. R. & Curtin, J. J. Alcohol stress response dampening: Selective reduction of anxiety in the face of uncertain threat. *J. Psychopharmacol. (Oxf.)* **26**, 232–244 (2012).

96. Fairbairn, C. E., Kang, D. & Federmeier, K. D. Alcohol and neural dynamics: A meta-analysis of acute alcohol effects on event-related brain potentials. *Biol. Psychiatry* **89**, 990–1000 (2021).

97. Fachner, J. An Ethno-Methodological Approach to Cannabis and Music Perception, with EEG Brain Mapping in a Naturalistic Setting. *Anthropol. Conscious.* **17**, 78–103 (2006).

98. Green, P. & MacLeod, C. J. SIMR : an R package for power analysis of generalized linear mixed models by simulation. *Methods Ecol. Evol.* **7**, 493–498 (2016).

99. Watson, P. E., Watson, I. D. & Batt, R. D. Prediction of blood alcohol concentrations in human subjects. Updating the Widmark Equation. *J. Stud. Alcohol* **42**, 547–556 (1981).

100. Widmark, E. M. P. Die theoretischen Grundlagen und die praktische Verwendbarkeit der gerichtlich-medizinischen Alkoholbestimmung. *Urban & Schwarzenberg* (1932).

101. Fairbairn, C. E. *et al.* Speech volume indexes sex differences in the social-emotional effects of alcohol. *Exp. Clin. Psychopharmacol.* **23**, 255–264 (2015).

102. Testa, M. *et al.* Understanding alcohol expectancy effects: Revisiting the placebo condition. *Alcohol. Clin. Exp. Res.* **30**, 339–348 (2006).

103. Fairbairn, C. E. *et al.* Extraversion and the rewarding effects of alcohol in a social context. *J. Abnorm. Psychol.* **124**, 660–673 (2015).

104. Fairbairn, C. E. & Sayette, M. A. The effect of alcohol on emotional inertia: A test of alcohol myopia. *J. Abnorm. Psychol.* **122**, 770–781 (2013).

105. Aron, A., Aron, E. N. & Smollan, D. Inclusion of Other in the Self Scale and the structure of interpersonal closeness. *J. Pers. Soc. Psychol.* **63**, 596–612 (1992).

106. Creswell, K. G. *et al.* Perceived Group Reinforcement Scale. https://doi.org/10.1037/t27569-000 (2014).

107. Miltner, W. H. R., Braun, C. H. & Coles, M. G. H. Event-Related Brain Potentials Following Incorrect Feedback in a Time-Estimation Task: Evidence for a "Generic" Neural System for Error Detection. *J. Cogn. Neurosci.* **9**, 788–798 (1997).

108. Yeung, N. & Sanfey, A. G. Independent Coding of Reward Magnitude and Valence in the Human Brain. *J. Neurosci.* **24**, 6258–6264 (2004).

109. Picton, T. W. *et al.* Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology* **37**, 127–152 (2000).

110. Dale, A. M. Source localization and spatial discriminant analysis of event-related potentials: Linear approaches (brain cortical surface). *Diss. Abstr. Int.* **55**, (1994).

111. Proudfit, G. H. The reward positivity: From basic research on reward to a biomarker for depression: The reward positivity. *Psychophysiology* **52**, 449–459 (2015).

112. Hauser, T. U. *et al.* The feedback-related negativity (FRN) revisited: New insights into the localization, meaning and network organization. *NeuroImage* **84**, 159–168 (2014).

113. Somerville, L. H., Heatherton, T. F. & Kelley, W. M. Anterior cingulate cortex responds differentially to expectancy violation and social rejection. *Nat. Neurosci.* **9**, 1007–1008 (2006).

114. Lavin, C. *et al.* The anterior cingulate cortex: an integrative hub for human socially-driven interactions. *Front. Neurosci.* **7**, (2013).

115. Eisenberger, N. I., Lieberman, M. D. & Williams, K. D. Does Rejection Hurt? An fMRI Study of Social Exclusion. *Science* **302**, 290–292 (2003).

116. Fairbairn, C. E. & Kang, D. Social Drinking and Addiction: A Social-Cognitive Model for Understanding Alcohol Use Disorder Risk. *Current Directions in Psychological Science* (In press).

117. Chang, L. J., Doll, B. B., Van ’T Wout, M., Frank, M. J. & Sanfey, A. G. Seeing is believing: Trustworthiness as a dynamic belief. *Cognit. Psychol.* **61**, 87–105 (2010).

118. Fareri, D. S., Chang, L. J. & Delgado, M. R. Effects of Direct Social Experience on Trust Decisions and Neural Reward Circuitry. *Front. Neurosci.* **6**, (2012).

119. Baumeister, R. F. & Leary, M. R. The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychol. Bull.* **117**, 497–529 (1995).

120. Clark, M. S. & Lemay, E. P. Close Relationships. in *Handbook of Social Psychology* (eds Fiske, S. T., Gilbert, D. T. & Lindzey, G.) (McGraw Hill, Boston, 2010).

121. Thoma, P. & Bellebaum, C. Your error’s got me feeling–how empathy relates to the electrophysiological correlates of performance monitoring. *Front. Hum. Neurosci.* **6**, 135 (2012).

122. Yu, H. *et al.* Your Performance Is My Concern: A Perspective-Taking Competition Task Affects ERPs to Opponent’s Outcomes. *Front. Neurosci.* **13**, 1162 (2019).

123. Euser, A. S., Van Meel, C. S., Snelleman, M. & Franken, I. H. A. Acute effects of alcohol on feedback processing and outcome evaluation during risky decision-making: an ERP study. *Psychopharmacology (Berl.)* **217**, 111–125 (2011).

124. Steele, C. M., Southwick, L. & Pagano, R. Drinking your troubles away: The role of activity in mediating alcohol’s reduction of psychological stress. *J. Abnorm. Psychol.* **95**, 173–180 (1986).

125. Steele, C. M. & Josephs, R. A. Drinking your troubles away II: An attention-allocation model of alcohol's effect on psychological stress. *J. Abnorm. Psychol.* **97**, 196–205 (1988).

126. Yang, H., Duan, Q., Peng, M., Gu, R. & Sun, X. Sex differences on the response to others' gains and losses under cooperation and competition. *Int. J. Psychophysiol.* **182**, 211–219 (2022).

127. Peterburs, J. *et al.* Processing of fair and unfair offers in the ultimatum game under social observation. *Sci. Rep.* **7**, 44062 (2017).

128. Huberth, M. *et al.* Performance monitoring of self and other in a turn-taking piano duet: A dual-EEG study. *Soc. Neurosci.* **14**, 449–461 (2019).

129. Kang, S. K., Hirsh, J. B. & Chasteen, A. L. Your mistakes are mine: Self-other overlap predicts neural response to observed errors. *J. Exp. Soc. Psychol.* **46**, 229–232 (2010).

130. Redcay, E. & Schilbach, L. Using second-person neuroscience to elucidate the mechanisms of social interaction. *Nat. Rev. Neurosci.* **20**, 495–505 (2019).

131. Novembre, G. & Iannetti, G. D. Hyperscanning alone cannot prove causality. Multibrain stimulation can. *Trends Cogn. Sci.* **25**, 96–99 (2021).

132. Larson, M. J., Fair, J. E., Good, D. A. & Baldwin, S. A. Empathy and error processing. *Psychophysiology* **47**, 415–424 (2010).

133. Santesso, D. L. & Segalowitz, S. J. The error-related negativity is related to risk taking and empathy in young men. *Psychophysiology* **46**, 143–152 (2009).

134. Keren, H. *et al.* Reward Processing in Depression: A Conceptual and Meta-Analytic Review Across fMRI and EEG Studies. *Am. J. Psychiatry* **175**, 1111–1120 (2018).

135. Chartier, K. & Caetano, R. Ethnicity and health disparities in alcohol research. *Alcohol Res. Health J. Natl. Inst. Alcohol Abuse Alcohol.* **33**, 152–160 (2010).

136. Heath, D. B. *Drinking Occasions: Comparative Perspectives on Alcohol & Culture*. (Routledge, Philadelphia, 2000).

137. Chrzan, J. *Alcohol: Social Drinking in Cultural Context.* (Routledge, New York, 2013).

138. Huang, M.-H. & Chang, S.-H. Similarities and Differences in East Asian Confucian Culture: A Comparative Analysis. *OMNES J. Multicult. Soc.* **7**, 1–40 (2017).

139. Nichols, R. Civilizing Humans with Shame: How Early Confucians Altered Inherited Evolutionary Norms through Cultural Programming to Increase Social Harmony. *J. Cogn. Cult.* **15**, 254–284 (2015).

140. Guo, Z., Sameen, D., Al-Khaz'Aly, H. & Jin, L. The linear and curvilinear relationships between assertiveness and mental health: a cross-cultural perspective. *Couns. Psychol. Q.* **38**, 88–108 (2025).

141. Ma, Z. & Jaeger, A. M. A comparative study of the influence of assertiveness on negotiation outcomes in Canada and China. *Cross Cult. Manag. Int. J.* **17**, 333–346 (2010).

142. Russell, J. A. Core affect and the psychological construction of emotion. *Psychol. Rev.* **110**, 145–172 (2003).