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BRIEF REPORT

Alcohol's Effects on Decision Making and Cognitive Processing in a Reward Uncertainty Task

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Objective: Alcohol impairs judgment, often increasing risk-taking behaviors such as reckless driving and gambling, which can result in severe consequences. However, laboratory studies have inconsistently observed alcohol-induced risk taking, raising questions about the specific contexts in which these effects emerge. This study investigated alcohol's impact on decision making within a reward uncertainty framework. ***Method:*** Participants were given a moderate dose of alcoholic ($N = 40$), placebo ($N = 40$), or a nonalcoholic drink ($N = 42$) before completing a validated Reward Uncertainty Task in which they chose between certain and uncertain monetary rewards. ***Results:*** Nonintoxicated participants demonstrated an expected aversion to uncertainty, favoring certain rewards even when objectively less advantageous. Alcohol appeared to reduce this reward uncertainty aversion. No placebo effects were observed, indicating a pharmacological rather than expectancy effect. We also explored the neural mechanisms underlying these behaviors using the P3 event-related potential. Alcohol significantly attenuated the P3 response to choice presentations, reflecting disrupted cognitive processing, potentially facilitating riskier choices. ***Conclusions:*** These findings complement previous research that showed alcohol dampens responses to uncertain aversive stressors, with a novel extension from aversive to appetitive domains. Future research should explore nuances in these effects to help aid targeted interventions for mitigating alcohol's negative impact on decision making.

Public Health Significance Statement
This study used a validated decision-making task focused specifically on reward uncertainty, which is a factor often overlooked in alcohol research. It shows that alcohol reduces uncertainty aversion and impairs brain responses involved in evaluating choices, helping explain when and why intoxicated individuals make risky decisions.

Keywords: alcohol, decision making, uncertainty, reward, event-related potential

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For centuries, alcohol has been recognized for lowering inhibition and distorting risk perception, fueling consequential risky behaviors such as reckless driving, unprotected sex, and excessive gambling (Davis-Stober et al., 2019; George et al., 2024; Horn et al., 2022). Clearer mechanistic understanding of when alcohol affects risk taking is crucial for developing strategies to mitigate these negative effects. Moreover, understanding alcohol's influence on decision making can clarify preferences for immediate, certain, or expected

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rewards that contribute to the maintenance of alcohol use disorders (Bradford et al., 2017).

Laboratory studies have progressed toward uncovering when alcohol affects risk taking, often using computer gambling tasks to probe involved mechanisms (see Horn et al., 2022, for review). These tasks allow researchers to precisely measure cognitive-behavioral responses and manipulate participant intoxication and reward contingencies. However, a meta-analysis of 20 studies using gambling tasks found no significant effect of alcohol on risk taking (Horn et al., 2022). These null findings may reflect oversight of critical contextual factors that shape alcohol's influence on decision making.

One such factor involves human behavior in the face of uncertainty, a common feature of real-world decisions. Humans typically avoid risky uncertain outcomes (Tversky & Kahneman, 1974), contributing to more conservative choices. Alcohol may reduce this uncertainty aversion, providing a mechanistic pathway through which intoxication can increase risk taking. This would parallel alcohol's propensity to dampen stress reactivity to uncertain (e.g., unpredictably delivered aversive stimuli, stranger interactions) more than to certain stressors (e.g., predictably delivered aversive stimuli, standardized tests; Bradford et al., 2017, 2022; Fairbairn & Sayette, 2014; Kaye et al., 2017). Notably, overlapping neural and psychological mechanisms for processing uncertainty involving stressors and rewards suggest common pathways for alcohol's dampening effects (Grupe & Nitschke, 2013). By taking early steps toward bridging the gap between laboratory findings and real-world behaviors, studies that isolate the role of reward uncertainty, a common real-world feature, may help identify when alcohol's impact on risk taking is most salient.

Understanding the cognitive-attentional and neural mechanisms driving these effects is similarly important. Brain-wave event-related potentials (ERPs; Luck, 2012) help illuminate such mechanisms underlying alcohol's impact as they offer excellent temporal resolution, making them particularly well-suited for capturing rapid, dynamic changes in cognitive processing that occur during choice evaluation. Specifically, the P3 is a positive-going ERP component that typically peaks between 300 and 400 ms poststimulus and is widely interpreted as indexing cognitive resource allocation and attentional engagement (Luck, 2012). It is sensitive to motivationally relevant stimuli and has provided insight into how the brain evaluates decision-relevant information in both sober and intoxicated contexts. Alcohol's disruption of cognitive processes, measured by P3, can provide critical insights into the neural mechanisms underlying impaired risk evaluation when intoxicated (Bradford et al., 2017).

This brief report describes the effects of a moderate alcohol dose in a validated decision-making task (Hefner et al., 2016) that manipulates reward certainty. To account for potential alcohol expectancy effects (Horn et al., 2022), we compared responses from intoxicated participants to nonintoxicated, no-alcohol, and placebo groups. We expected nonintoxicated participants to show natural preferences for certain over uncertain rewards (Hefner et al., 2016; Tversky & Kahneman, 1974), also expecting alcohol to reduce this uncertainty aversion (Bradford et al., 2017; Kaye et al., 2017). Additionally, we measured the P3 component to explore alcohol's influence on reward evaluation. We expected that alcohol would disrupt reward processing, increasing the tendency to choose uncertain rewards.

Method

We recruited 122[1] participants (60 female; $M_{age} = 22.4$, 96% non-Hispanic; 82% White, 15% Asian, 3% Black) from the university community. An a priori but not preregistered power analysis approximated power for the present study, indicating that this sample size provided at least 80% power at α level of .05 to detect the median effect size ($\eta_p^2 = .07$) from prior studies using linear models to assess alcohol's effects on stress reactivity under uncertain versus certain stressors when assuming multiple covariates (e.g., Bradford et al., 2022). Eligibility criteria included the following: being aged 21–35, able to read/write English, experience drinking the study dose of alcohol within the past year, no history of alcohol problems, no current psychiatric medication, no uncorrected sensory issues, no contraindicated medical conditions, not pregnant (verified via urinalysis), and currently sober (verified via breathalyzer, Alcosensor IV; Intoximeters Inc., St. Louis, Missouri). Participants received $7.50/hr for participation.

The Reward Uncertainty Decision-Making Task is described in greater detail by Hefner et al. (2016). In brief, 108 trials of "certain" and "uncertain" monetary rewards were represented by two adjacent circles on a computer screen. Certain reward choices featured single monetary values; uncertain choices displayed a low or high potential value (examples in Figure 1). Participants indicated preference by pressing one of two buttons for either choice. Participants were incentivized with the promise of receiving payment based on one randomly selected trial. Responses were expected within 4 s, with a penalty of forfeiting the randomly selected trial payment if responding late. After a brief instruction phase and practice trials to ensure comprehension, the task took roughly 10 min to complete.

Consistent with our prior work on uncertainty (Bradford et al., 2017, 2022), this brief report focuses on the task's primary manipulation of uncertainty, allowing novel focus on alcohol's effects on uncertain versus certain reward choices. However, as the task was originally designed to test other hypotheses in a different sample, uncertain reward choices in the Reward Uncertainty Task also varied across trials systematically in the following: (a) utility—the extent to which uncertain reward was objectively disadvantageous (negative) or advantageous (positive), calculated as 0.5 × (low value + high value) − certain value, ranging from −4 to +4, with 0 indicating reward equivalency; (b) variance—the difference between uncertain reward values (either low, $10, vs. high, $50); and (c) uncertainty type—trials with known (e.g., 50%) probability versus unknown probabilities (see Hefner et al., 2016, for more details about these nonfocal manipulations).

P3 ERP

Electroencephalography data were sampled at 2500 Hz from 12 midline scalp sites (see Supplemental Materials). P3 ERP amplitudes were measured at electrode site Pz in response to reward choice onset, consistent with our recent work (Bradford et al., 2017, 2022) and scored 271–371 ms posttrial onset when P3 was maximal based on visual inspection of the grand–grand average waveforms.

[1] Data collection failures resulted in preoutlier removal of two (data saving errors) and three (electrodes detaching) participants for behavioral and ERP results, respectively. Outlier analyses resulted in removal of 1–4 outliers (see the Supplemental Materials).

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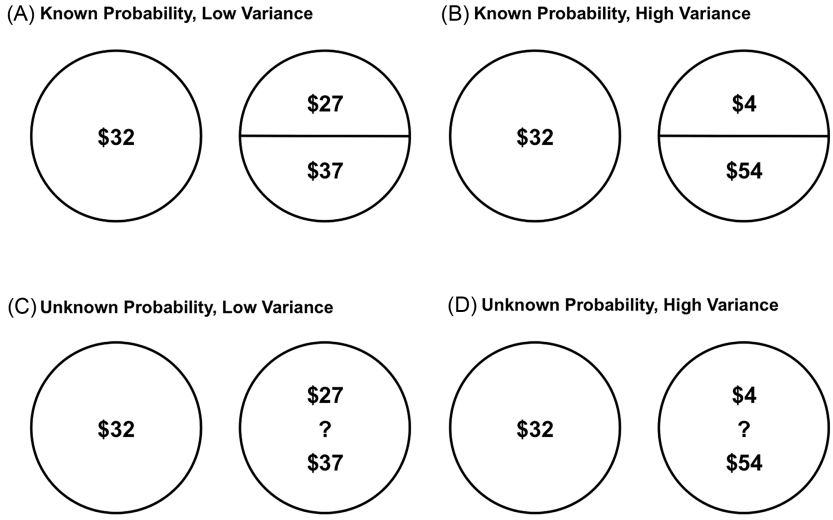
Figure 1
Reward Uncertainty Task Design



Note. Reproduced from "Altered Subjective Reward Valuation Among Drug-Deprived Heavy Marijuana Users: Aversion to Uncertainty," by K. R. Hefner, M. J. Starr, and J. J. Curtin, 2016, *Journal of Abnormal Psychology*, *125*(1), p. 142 (https://doi.org/10.1037/abn0000106). Copyright 2016 by the American Psychological Association: Trials presented rewards under certain and uncertain conditions. Uncertain rewards were manipulated across two dimensions: *uncertain reward variance* (low: $10 vs. high: $50) and *uncertainty type* (known vs. unknown probability). (A) Trial with low uncertain reward variance ($10). (B) Known probability trial with high uncertain reward variance ($50). (C) Unknown probability trial with low ($10) uncertain reward variance. (D) Unknown probability trials with low ($10) and high ($50) uncertain reward variance, respectively. The present study investigated choices between uncertain and certain rewards across task conditions.

Electroencephalography response reduction and processing followed established guidelines and our previous work (Bradford et al., 2022; see the Supplemental Materials).

Beverage Manipulation

Participants were randomized into three beverage groups: $N = 40$ alcohol, $N = 40$ placebo (i.e., told alcohol, no alcohol), and $N = 42$ true no-alcohol (i.e., told no alcohol, no alcohol). The alcohol group's beverages contained vodka (100-proof Smirnoff Blue Label) dosed to generate a blood alcohol concentration (BAC) of 0.08%, calculated based on participants' biological sex assigned at birth, age, height, and weight (Curtin & Fairchild, 2003). Placebo and no-alcohol beverages contained water instead of vodka but matched the juice mixer volume of the alcohol group. Beverage manipulation procedures matched laboratory standards (e.g., Bradford et al., 2022; see the Supplemental Materials for placebo manipulation details). We informed participants in the alcohol and placebo groups that they would receive a moderately impairing dose of alcohol, equivalent to approximately three standard drinks consumed by a 160-lb man within an hour. Participants in the placebo condition received a beverage made from fruit juice mixed with water, poured from a vodka bottle in their presence. To support the placebo manipulation, we misted both the alcohol and placebo beverages with 200-proof alcohol and floated 2 mL of 200-proof alcohol on top of the placebo drinks for sensory stimulation.

Open Science Practices

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study (Simmons et al., 2011). Curated data and analysis scripts are publicly available at https://osf.io/8cj7n/ (Whittaker et al., n.d.). In the absence of a preregistration, the analyses should be considered exploratory. However, we reduced "researcher degrees of freedom" and guarded against α inflation by using the exact analyses model from the only other published use of the Reward Uncertainty Task (Hefner et al., 2016) with two exceptions: (a) testing separate effects for alcohol and placebo groups as required by the novel beverage manipulation and (b) performing outlier detection for choice data using individual DFBETAS rather than the overall model (see the Supplemental Materials).

Analysis Plan

We modeled the odds of choosing uncertain or certain reward for each trial using a two-level generalized linear mixed effects model (lme4 R package; Bates et al., 2015). Focal analyses included fixed effects for beverage group (planned orthogonal contrasts for alcohol vs. others, and placebo vs. true no-alcohol), random effects for the intercept, and fixed and random effects for within-subject trial-level variables. We directly replicated Hefner et al.'s (2016) analyses, which included sex and interactions with utility, variance, and uncertainty type as fixed and random effects. P3 ERPs were analyzed

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using equivalent linear models rather than mixed models due to the need to average ERP trials per condition and subject to optimize signal-to-noise ratio (Luck, 2012). We report, where appropriate, predicted probabilities, raw parameter estimates (*B*s), change in odds ratios (*OR*), and partial eta squared (η_p^2) for effect sizes.

Results

Mean BAC for alcohol participants was 0.08% (*SD* = 0.02%) before the task and 0.08% (*SD* = 0.01%) after. The placebo manipulation successfully established expectations of alcohol intoxication. For example, placebo participants estimated their BAC to be significantly above 0 (BAC = .07), $\eta_p^2 = .06$, $B = .07$, $t(119) = 2.70$ (see the Supplemental Materials).

At utility = 0, participants in the alcohol group chose the uncertain reward on 32% (95% confidence interval, CI [.24, .42]) of trials compared to 24% (95% CI [.21, .27]) in the true no-alcohol group and 25% (95% CI [.17, .34]) in the placebo group. Nonintoxicated participants were significantly less likely to choose the uncertain (relative to the certain) reward when the uncertain and certain rewards had equal value (utility = 0), $B = -1.15$, $z = 13.49$, $p < .001$, $OR = 0.32$, indicating uncertainty aversion. This aversion was significantly reduced in the alcohol group, as indicated by a significant Beverage × Certainty interaction, $B = 0.45$, $z = -2.34$, $p = .019$, $OR = 1.57$ (Figure 2). The placebo group did not differ from the no-alcohol group in this aversion, $B = .04$, $z = .18$, $p = .856$, $OR = 1.04$.

Nonintoxicated participants displayed a significant P3 ERP when presented with the reward choices, $\eta_p^2 = .58$, $B = 7.06$, $t = 12.66$, $p < .001$. Alcohol significantly reduced the overall P3 ERP, $\eta_p^2 = .06$, $B = -2.82$, $t = -2.87$, $p = .005$, whereas the placebo had no effect, $\eta_p^2 = .00$, $B = 0.02$, $t = .02$, $p = .988$. No other interactions involving alcohol or placebo were statistically significant. We report auxiliary task manipulation checks and results involving other nonfocal task variables in the Supplemental Materials.

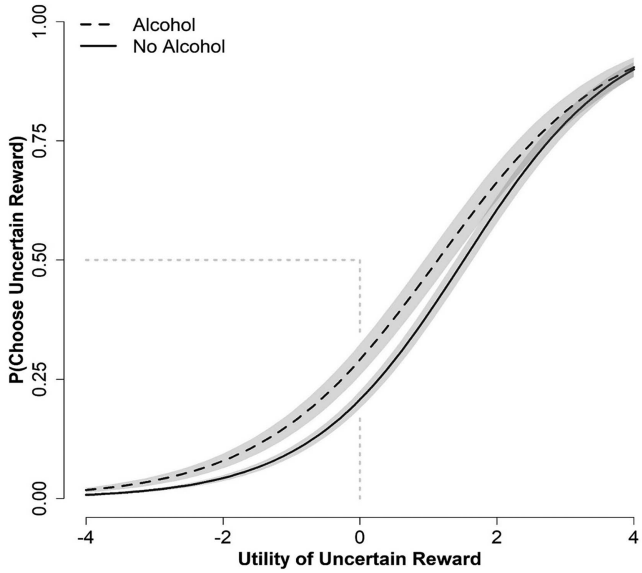
Discussion

Although alcohol is colloquially known to increase risk-taking behaviors, inconsistent laboratory findings have raised questions about the specific conditions driving this effect (Horn et al., 2022). We explored alcohol's effects under explicit reward uncertainty. Consistent with prior work (Hefner et al., 2016; Tversky & Kahneman, 1974), nonintoxicated participants showed a strong preference for certain rewards, even when the uncertain rewards were of equal objective value. Intoxicated participants were over 1.5 times more likely to choose uncertain rewards, suggesting that alcohol significantly reduces uncertainty aversion. No placebo effects emerged, suggesting that alcohol's pharmacological effects, not expectancy, were primarily driving increased preference for uncertain rewards that may manifest as increased intoxicated risk taking.

We also explored neural mechanisms underlying this effect by measuring the P3 component (Bradford et al., 2022). Alcohol significantly attenuated P3 responses to reward options, suggesting broadly impaired evaluation of decision-relevant information and reduced cognitive control. Alcohol's attenuation of P3 may divert attention away from outcome evaluation, contributing to defaulting to choosing immediate, certain rewards (Bradford et al., 2017). This compromised processing of potential consequences may exacerbate increases in intoxicated risk-taking behaviors.

Figure 2

Probability of Choosing Uncertain Reward by Utility of Choosing Uncertain Reward



Note. Black lines represent the predicted probabilities of choosing the uncertain reward for the alcohol and no-alcohol (combined true no-alcohol and placebo) participants from the generalized linear mixed effects models. Gray bands represent ±1 standard error for predicted probabilities. Utility −4 to +4 indicates the extent to which uncertain reward was objectively disadvantageous or advantageous, calculated as 0.5 × (two uncertain values − certain value). Although utility was not a focal predictor, the full range is shown to contextualize the task structure and highlight the point of primary interest: Utility = 0, where certain and uncertain rewards were objectively equivalent. Gray dotted lines intersect at utility = 0 and 50% probability, showing the point where choosing either reward would be objectively equally advantageous.

Although this study targeted uncertainty preference broadly, alcohol's effects appeared consistent across more nuanced variations in reward utility and variance (see the Supplemental Materials). This suggests that alcohol may reduce uncertain reward avoidance even in situations when stakes are low and difficult to discern *and* when stakes are high and consequences potentially devastating. While this result has broad implications for alcohol's effects on decision making, it should be taken cautiously as the current exploratory study was not designed nor adequately powered to observe nuanced interactions between alcohol and reward characteristics such as utility and variance. For example, alcohol may particularly reduce avoidance of high-variance uncertain rewards, where the potential for large gains coexists with the possibility of large losses, thereby amplifying risk taking when stakes are most consequential. Similarly, alcohol broadly attenuated the P3 response, appearing insensitive to reward-specific attributes such as reward certainty. Larger samples and additional measures of emotion and attention (e.g., defensive startle potentiation, eye tracking) are needed to corroborate and clarify these findings.

These findings align with broader research showing alcohol's disrupting effects on responses to uncertainty in other domains. Across programmatic studies, we have consistently shown that alcohol dampens stress reactivity to uncertain stressors more so than

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to certain stressors (Bradford et al., 2017, 2022; Bradford et al., 2022). This effect spans stressor types (e.g., electric shock, darkness; Whittaker et al., 2024), uncertainty type (e.g., unpredictable timing, location), response domains (e.g., reflexive defensive reactivity, self-reported anxiety), and other stressor characteristics (e.g., controllability, intensity). Here, alcohol's dampening effects on the processing of uncertainty appeared to extend from the aversive to the appetitive domain, suggesting common psychological and/or neural mechanisms in the modulation of risk-taking behavior when intoxicated (Grupe & Nitschke, 2013).

The only previous study using the Reward Uncertainty Task observed increased reward uncertainty aversion in deprived frequent marijuana users, attributed to possible drug-induced neuroadaptations increasing sensitivity to uncertainty for frequent users (Hefner et al., 2016). Cross-drug animal models of drug addiction suggest repeated alcohol use and withdrawal may engage similar neural mechanisms (Kaye et al., 2017; Moberg et al., 2017). The reduced uncertainty aversion observed here may indicate the first step in a neuroadaptive process linked to alcohol and other drug addiction. Future research should examine alcohol-deprived frequent, heavy drinkers to explore how chronic alcohol use modulates neural responses to reward uncertainty, potentially driving preferences for immediate or certain rewards often observed in alcohol use disorder (Hefner et al., 2016; Kaye et al., 2017; Moberg et al., 2017).

This study addresses how and when alcohol affects decision making, emphasizing initial evidence of its role in modulating responses to uncertain rewards. Future work with more diverse samples (less limited in generalizability like the current primarily college student sample) and preregistered hypotheses examining dose, delayed rewards, and individual differences (e.g., impulsivity, risk or uncertainty tolerance; Morriss et al., 2023) will further clarify conditions and individuals wherein these effects occur. Additionally, future studies should examine whether alcohol's effects on uncertainty aversion generalize to decisions involving potential losses or other punishment not considered here, given known asymmetries in risk-taking behavior across gain and loss domains (Rangel et al., 2008). Using methods such as ecological momentary assessment to track real-time uncertainty perception and risky decision making in naturalistic contexts could enhance ecological validity and test whether the laboratory-observed reductions in uncertainty aversion extend to everyday behaviors (Goodman et al., 2022). Such work is critical for developing interventions to mitigate alcohol's harmful effects on risk-taking behavior and addictive use.

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