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Alcohol-Related Craving and Response Inhibition: Examining Effects of Mindfulness Among Binge Drinking and Cannabis Using College Students

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William & Mary - Arts & Sciences

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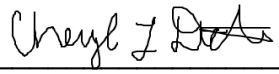

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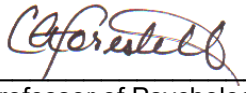

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COMPLIANCE PAGE

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ABSTRACT

The present study aimed to examine several research questions related to alcohol craving, state mindfulness, and response inhibition in binge drinking college students who do and do not use cannabis. Before and after listening to a mindfulness or a control audio clip, participants (*N* = 30) completed a cued Go/NoGo task. EEG activity was measured throughout, and alcohol craving was assessed before and after each task. We examined whether P300 amplitude would differ as a function of the within-subjects variables Block (1 vs. 2), Target (Go vs. NoGo), and Cue (Alcohol vs. Neutral) of each task. We also examined if P300 amplitudes to alcohol cues would be affected by craving for alcohol and/or a short mindfulness induction, and whether craving for alcohol would be affected by a short mindfulness induction.

Results were in partial alignment with previous literature, showing larger amplitude P300 ERPs for alcohol compared to neutral stimuli. Counter to previous work, however, this occurred in Go rather than NoGo trials. Craving was not found to be involved in the relationship. Additionally, time point of craving and audio manipulation were found to interact such that craving immediately after the audio manipulation (relative to immediately before) was reduced in both groups, but to a greater extent in the mindfulness compared to control group. Exploratory analyses related to cannabis use did not provide evidence that concurrent alcohol and cannabis use were associated with P300 amplitudes.

In conclusion, recent research suggests that neural measures of response inhibition, like the P300 ERP, may be useful for identifying and tracking changes in functional responses to substance use-related stimuli. P300 ERPs show potential for advancing the identification, understanding, and treatment of addictive behaviors related to alcohol and other drugs. Going forward, research should examine how mindfulness may be associated with inhibition-related processing of substance use-related stimuli, especially in populations with greater levels of craving and craving variability. Significant study limitations are identified and discussed.

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ACKNOWLEDGEMENTS

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Alcohol-Related Craving and Response Inhibition: Examining Effects of Mindfulness Among Binge Drinking and Cannabis Using College Students

Young adulthood is a crucial developmental time period in individuals' lives, and is associated with relatively high risk for initiating and escalating alcohol use (Schulenberg et al., 2018; White et al., 2005; 2006). Additionally, college students display higher levels of alcohol use and problem drinking behaviors compared to their non-college peers (Barnes et al., 2010), and roughly one third of young adults reporting binge drinking (i.e., 4+ drinks for females, 5+ for males, within a two-hour period) over the past month (Center for Behavioral Health Statistics and Quality, 2016; Schulenberg et al., 2019). Consequences associated with excessive drinking in college students may include reduced academic performance, injury, sexual assault, overdose, memory blackout, changes in brain function, cognitive deficits, and death (White & Hingson, 2013). There is evidence that alcohol may be associated with negative use-related neurocognitive consequences, especially in the context of adolescence and emerging adulthood. These include poor performance on tests of executive functioning, attention, working memory, and cognitive inhibition/inhibitory control (De Bellis et al., 2019; Lopez-Caneda et al., 2014; Nguyen-Louie et al., 2017; 2018).

Neuropsychological Theories of Addiction

A prominent theoretical model used to conceptualize and explain addictive behaviors is the incentive sensitization theory (Robinson & Berridge, 1993). The framework posits that drugs with addictive potential are capable of producing

long-term neuroadaptations, and these adaptations occur principally in regions involved in reward and incentive motivation. According to the theory, these brain systems undergo changes in some individuals who take drugs such that they become hypersensitive or sensitized to drug-related stimuli. Importantly, while these neurological adaptations are presumed to not mediate the pleasurable effects of drugs (drug “liking”), they are thought to be associated with a subcomponent of reward termed incentive salience, or drug “wanting” (Berridge & Robinson, 2016; Robinson & Berridge, 2000). Considering that addictive drug-seeking and consummatory behaviors depend on drug “wanting” or increased motivational salience toward drug-related stimuli, as well as an individual’s motivation and ability to resist that motivation (i.e., self-regulatory inhibitory control), models that highlight inhibitory functions in addictive behaviors are also valuable (Jentsch & Pennington, 2014).

The impaired Response Inhibition and Salience Attribution (iRISA) dual model of addiction has garnered empirical support and suggests that impairments in neuropsychological response inhibition and salience attribution contribute to addictive behaviors and symptoms broadly and similarly across different types of drugs (Zilverstand & Goldstein, 2020; Zilverstand et al., 2018). Response inhibition is conceptualized as the “ability to control and inhibit prepotent responses”, whereas salience attribution is conceptualized as the “ability to track, update, and modulate the salience of a reinforcer as a function of context and expectation” (Goldstein & Volkow, 2002). There is evidence that altered functioning of six higher-order brain networks (reward, salience,

executive, self-directed, habit, and memory networks) are linked to impairments in response inhibition and salience attribution in human drug addiction. Zilverstand and colleagues (2018) compiled results from 105 neuroimaging studies in individuals addicted to various drugs to show that abnormal activity in the reward and salience networks can contribute to altered incentive salience towards drug (increased salience) and non-drug (decreased salience) related stimuli, while abnormal activity in the salience and executive networks can contribute to impairments in response inhibition. The authors also suggest that changes in the habit, memory, and self-directed networks contribute to impairments in both response inhibition and salience attribution by altering underlying learning processes. The impairments in response inhibition and salience attribution observed in the review were consistent across different populations of individuals suffering from different drug addictions, offering a common model for explaining the relationships among neural mechanisms, neuropsychological functioning, and addiction-related symptoms like craving, intoxication, bingeing, and withdrawal (Zilverstand & Goldstein, 2020; Zilverstand et al., 2018). Thus, theory and evidence suggest that impaired response inhibition is one broad indicator of addiction and related problems.

Response inhibition is commonly investigated using laboratory tasks like Go/NoGo, stop signal, Stroop, and cognitive reappraisal tasks (Zilverstand et al., 2018). These types of tasks examine processes of cognitive control via behavioral performance (i.e., reaction times and commission errors, or “false alarms”, where participants will press a button under conditions they were

instructed not to). For example, in a Go/NoGo task, participants will be presented with two types of targets (Go vs. NoGo), and instructed to press a button as fast as possible in response to Go targets and to withhold a button press in response to NoGo targets. Accordingly, Go and NoGo conditions are created, and behavioral as well as other types of responses can be measured and compared by condition. Other factors including cue type (drug vs. neutral) as well as probability (i.e., 80% vs. 20% chance of a particular condition occurring) can also be manipulated within a Go/NoGo task to examine drug vs. neutral related processing in a context where a prepotent response is required to be inhibited. For example, the first block of a task with 80% alcohol-Go, 20% alcohol-NoGo stimuli and then a second block with 80% alcohol-NoGo, 20% alcohol-Go stimuli, requires participants to inhibit in block 2 the learned association between 'Alcohol' and 'Go' from block 1.

Neural processing specific to response inhibition is often measured using event-related potentials (ERPs) derived from electroencephalography (EEG). EEG measures of response inhibition include frontal-midline N200/theta oscillations, thought to indicate premotor processes like conflict monitoring and response updating, as well as anterior P300/delta oscillations, thought to indicate evaluative processes related to a response or motor inhibition (Fleming & Bartholow, 2014; Harper et al., 2014; Huster et al., 2013).

Alcohol EEG Studies

A recent meta-analysis by Zhang and colleagues found that, among individuals with substance use disorders (SUD), compared to healthy controls,

the P300 was augmented in response to drug cues and the N200 was attenuated in NoGo trials of Go/NoGo tasks. These results demonstrated high consistency among the 60 studies examined (which included SUDs related to stimulants and depressants), and the authors conclude that the P300 and N200 ERPs represent potential biomarkers for SUDs that can be used to track changes in functional recovery from addiction (Zhang et al., 2021). For alcohol specifically, results from studies included in the meta-analysis and in the literature more broadly are not homogenous. Some studies find significantly increased inhibition-related ERPs (i.e., P300 and/or N200) in individuals with problematic patterns of alcohol use for alcohol-related cues, compared to healthy controls (Petit et al., 2013; 2015), while others find significantly decreased inhibition-related ERPs (Oddy & Barry, 2009; Smith & Mattick, 2013), while still some others find no differences (Franken et al., 2017; Karch et al., 2007).

The contradictory state of the literature (see Zhang et al., 2021 for additional studies) may be attributable to several differences in study populations and methodologies. These differences include participants with diagnosed alcohol use disorder (AUD) vs. binge drinking patterns, their drug use status, sex composition of the samples, the type of tasks employed (e.g., Go/NoGo, passive/active picture viewing, stop signal, etc.), milliseconds post cue presentation that ERPs are examined within, and EEG sites used to measure ERPs and reference electrodes. Even so, it has been found that, in late-adolescence, poor response inhibition predicted alcohol-related problems and comorbid alcohol and drug use, while other executive functions did not (Nigg et

al., 2006). In college students, as impairments in response inhibition towards alcohol-specific stimuli have been found to predict binge-drinking patterns (Czapla et al., 2015), additional research is required to parse out potential differences in neural processing of alcohol cues in inhibition-related tasks in individuals who use alcohol.

Craving for Alcohol

Level of craving has been shown to be related to drug-related response inhibition. In an analysis of individuals with and without AUD, Batschelet et al. (2021) found that greater craving was associated with significantly larger amplitudes for alcohol NoGo N200 ERPs compared to neutral NoGo N200 ERPs, and this difference was not seen in Go trials. In contrast, no differences in ERP responses were found among abstinent individuals with AUD and healthy controls.

Further, differences in the NoGo P300 ERP were observed in the AUD group, but only in individuals who, three months following discharge from treatment, reported having relapsed, while those who had reported having abstained as well as non-AUD controls did not show differences in the NoGo P300 three months prior. Those who relapsed showed more negativity in right sided frontal electrodes for alcohol (vs. neutral) trials during NoGo trials, while in Go trials the opposite pattern was found. This indicates that neurophysiological ERP components correlated with inhibition and craving may be indicators for risk of relapse in individuals with AUD (Batschelet et al. 2021). Another study found that only in subjects with strong craving for alcohol, regardless of whether they

had a diagnosis of AUD, the NoGo N200 showed a greater amplitude in response to alcohol stimuli, presumably reflecting more effortful successful inhibitions related to alcohol stimuli (Stein et al., 2018). In detoxified AUD patients, another study found that individuals exposed to an alcohol craving induction procedure reported significantly greater craving, and displayed higher percentages of commission errors towards alcohol stimuli when compared to the control group (Kreusch et al., 2017). Given associations among craving, response inhibition, and the development of AUD and related problems, researchers have begun to examine protective factors that may attenuate the relationship between greater alcohol craving and deficits in response inhibition.

Mindfulness as a Protective Factor

There is evidence that mindfulness training impacts key mechanisms related to substance dependence, including automatic cognitive mechanisms in dual-process models like attentional biases and inhibitory processes (Garland et al., 2014; Moore & Malinowski, 2009). Mindfulness-based relapse prevention (MBRP) has been found to effectively reduce craving for substances and reduce substance use behaviors (Bowen et al., 2009; Brewer et al., 2013; Witkiewitz & Bowen, 2010), and the relationship between craving and substance use has been shown to be reduced by formal mindfulness practice (Enkema & Bowen, 2017). Mindfulness is thought to confer positive effects on substance use and related craving by enhancing cognitive regulation of a number of top-down mechanisms of addiction at the attention-appraisal-emotion interface. These include regulating negative emotions, decreasing attentional bias toward

addiction-related stimuli, reducing cue-reactivity, and improving cognitive control over craving (Garland et al., 2014; Rosenthal et al., 2021), though heterogeneity in the literature is extant (Im et al., 2021).

In college students, brief mindfulness instructions in a laboratory environment have elicited reductions in cigarette smoking behaviors, which may be a result of changes in how individuals respond to smoking urges (Bowen & Marlatt, 2009). In cigarette smokers who underwent a craving induction followed by either brief mindfulness or control instructions and a Go/NoGo task, reduced P300 amplitudes were observed for the mindfulness group on NoGo trials, indicating potentially less effortful response inhibition (Andreu et al., 2018). Accordingly, mindfulness training may work to decouple the relationship between the urge to smoke and associated deficits in response inhibition. With regard to alcohol, mindfulness has shown potential to reduce the urge to drink (Caselli et al., 2016), and it has been suggested that mindfulness-based strategies may extinguish craving by improving response inhibition (Tapper, 2018). Given mindfulness' attenuating relationship to alcohol craving, and deficits in response inhibition associated with greater levels of craving for alcohol, it may be the case that mindfulness and craving interact to predict performance on measures of response inhibition.

Alcohol and Cannabis Use

Cannabis use is common among young adults, with one in 17 high school seniors reporting daily use, and around 20% of college students reporting use in the past month (Johnston et al., 2018). Studies examining impairments in

executive functioning in individuals who use cannabis alone have been inconclusive, but point to deficits in neurocognitive and psychological functioning related to executive processes, attention, memory, learning, and psychomotor speed (Figueiredo et al., 2020; Grant et al., 2012; Hall et al., 2020; Lisdahl et al., 2014). One study found a persisting impact of cannabis use on decision making and executive planning, but reported no differences on a stop-signal reaction time (SSRT) task conducted in young people, though they only reported SSRT reaction times overall and on Go trials (Grant et al., 2012). On the other hand, neuroimaging studies suggest that cannabis acutely impairs general measures of inhibition (see Oomen et al., 2018 for a review), and Solowij et al. (1995) found that, in an auditory selective attention paradigm administered to individuals who used cannabis long-term, but were abstinent at the time of the study, P300 latency (but not amplitude) was significantly increased in individuals who used cannabis more frequently. Francis (2021) found that individuals who use cannabis display cannabis cue-related deficits in early attentional processing indexed by the N100 in a Go/NoGo task. Other studies suggest reduced neural activity in cannabis-dependent participants relative to healthy controls in cognitive control related regions (i.e., dorsolateral prefrontal cortex and dorsal anterior cingulate) while participating in a Stroop task (no drug cues), which related to less abstinence during treatment and at long-term follow up (Kober et al., 2014). Additionally, following two weeks of monitored abstinence, individuals who used cannabis displayed greater BOLD responses during correct response inhibitions regardless of the cue condition (interpretable as more effortful correct

inhibitions) in core brain areas associated with response inhibition during a Go/NoGo task (Wallace et al., 2020). Additional research is required to parse out differences in ERP components in inhibition-related tasks among individuals who use cannabis.

Further, simultaneous (i.e., use during the same occasion) and concurrent (i.e., use during a similar time period, for example over the past 30-days) use of alcohol and cannabis/marijuana (SAM and CAM, respectively) have been found to be common in college students around the world, with research finding around 75% of students who report using both substances over the past 30 days endorsing SAM (Bravo et al., 2021). While studies have found that both SAM and CAM use are associated with greater levels of alcohol use and associated negative consequences (Cummings et al., 2019), there is evidence that SAM use confers more deleterious effects (Jackson et al., 2020; Looby et al., 2021). The literatures related to alcohol and cannabis respectively provide evidence that impairments in response inhibition are associated with heavier use. But additional research is required to conclude which measures of response inhibition may be associated with each drug, the levels of drug use at which impairments are observed, and how interactions among use of different drugs might be associated with brain functions. Indeed, there is evidence that concurrent use of alcohol and cannabis is common in college students and associated with more consequences including AUD symptoms, greater levels of alcohol/cannabis use, and other daily drug use, compared to use of one drug only (Sokolovsky et al., 2020; Yurasek et al., 2017). Additionally, in adolescents

with alcohol (AUD) and/or cannabis use disorder (CUD), symptoms of each were found to be differentially related to brain functioning. Aloi and colleagues (2018) found that AUD symptoms were associated with amygdala hyperactivity to emotional stimuli, and with hypoactivity in regions related to executive attention and response control, whereas CUD symptoms were not associated with amygdala reactivity and related to hyperactivity in executive attention and cognitive control regions. Further, prior research has found that more co-use days of alcohol and cannabis are associated with poorer attentional capacity in adolescents and young adults following 3 weeks of abstinence (Wade, Bagot, et al., 2020). These results are consistent with other studies showing that white matter integrity in the cingulate gyrus, a key brain area related to attentional processes (Catani & Thiebaut de Schotten, 2012), were compromised in individuals with more co-use days over the previous month (Wade, Thomas, et al., 2020). In sum, there is evidence that dual use of both alcohol and cannabis may be associated with exacerbated deficits in cognitive performance and experience of negative consequences compared to alcohol or cannabis use alone (Hayaki et al., 2016; Jackson et al., 2020; Winward et al., 2014). Research is needed to examine associations between craving for alcohol and measures of alcohol-related response inhibition in people who use alcohol and cannabis use compared to alcohol only.

Present Study

Young adults and college students in particular are at high risk for developing AUD and experiencing associated negative consequences, and use

during this developmental period may be related to neurocognitive deficits in response inhibition, especially toward alcohol-related stimuli. The present research aimed to examine several research questions related to alcohol craving, state mindfulness, and response inhibition in binge drinking college students who do and do not use cannabis. Before and after listening to a mindfulness or a control audio clip, participants completed a cued Go/NoGo task with three within-subject factors: Block (80/20% chance of a Go/NoGo condition occurring for alcohol cues, 20/80% chance of a Go/NoGo condition occurring for neutral cues [block 1] vs. 20/80% chance of a Go/NoGo condition occurring for alcohol cues, 20/80% chance of a Go/NoGo condition occurring for neutral cues [block 2]), Target (Go vs. NoGo), and Cue (Alcohol vs. Neutral). EEG activity was measured throughout each task. Alcohol craving was assessed before and after each of the tasks. We wanted to know if P300 amplitudes differed based on each of the within-subjects variables of the Cued Go/NoGo task as well as the interactions between them, and whether craving for alcohol and a short mindfulness induction were associated with P300 amplitudes, especially under drug-inhibition-related trials (i.e., Alcohol-NoGo trials). We also wanted to know whether craving was affected by the mindfulness manipulation. We were also interested in testing if the brief mindfulness induction reduced craving for alcohol relative to control. We hypothesized that: 1) in task 1 (baseline: pre-audio manipulation), a three-way interaction among the factors Block (1 vs. 2), Target (Go vs. NoGo), and Cue (Alcohol vs. Neutral) would exist such that Alcohol-NoGo trials in block 2 (conflict condition) would show larger P300 amplitudes

compared to Neutral-NoGo trials in block 2, 2) the three-way interaction from hypothesis 1 will be moderated by craving for alcohol, such that greater craving is associated with larger P300 amplitudes in Alcohol-NoGo trials in block 2 of task 1, 3) craving would be attenuated by the brief mindfulness induction, 4) in task 2 (post-audio condition), a three-way Block (1 vs. 2), Target (Go vs. NoGo), and Cue (Alcohol vs. Neutral) interaction will be moderated by the between-subjects factor of audio manipulation (Mindfulness vs. Control), such that participants who received the mindfulness intervention will show reduced P300 amplitudes in Alcohol-NoGo relative to controls, and 5) in task 2, craving will moderate the hypothesized four-way interaction from hypothesis 4, such that P300 ERP amplitudes in block 2 alcohol-NoGo trials will be reduced in participants assigned to the mindfulness compared to control condition, especially for those reporting higher craving (i.e., larger reduction among those with higher craving).

Additionally, while many studies report the associations of a single substance's use on response inhibition, the literature generally lacks an examination of associations among response inhibition and CAM use. Alcohol and cannabis have to a large extent been found to be used concurrently in individuals who use recreationally (Bravo et al., 2021; Pacula et al., 2016), and use of cannabis has been found to moderate the effect of tobacco on response inhibition (Liu et al., 2019). Therefore, we sought to examine whether craving for alcohol differs among individuals who report alcohol only compared to CAM use, and whether task 1 (pre-audio manipulation) P300 ERP amplitudes in the various

conditions of the Go/NoGo task differed among individuals who report alcohol only vs. CAM use. While we had no *a priori* hypotheses as to how CAM use would relate to craving and P300 amplitudes in the task, findings from these exploratory analyses may point to future paths for research on alcohol-related response inhibition and craving.

Method

Participants

Participants were 31 (22 females [71%]; 9 males [29%]) undergraduate college students between the ages 18-22 years (M = 19.1; SD = 0.9) recruited from a medium-sized public liberal arts university in Virginia. Participants identified as White (26; 83.9%) and Asian (5; 16.1%), with 2 participants (6.4% of total) reporting Hispanic ethnicity. A breakdown of demographics by audio condition assigned (mindfulness vs. control) is presented in Table 1. All students participated for the partial fulfilment of a psychology introductory course requirement. To be eligible, participants must have binge drank (for males five or more, for females four or more, standard alcoholic drinks in a two-hour period) at least once in the previous 30 days. Participants were also required to have been right-handed, attend the laboratory session sober, and have no history of serious brain injury. All procedures were approved by William & Mary Protection of Human Subjects Committee, and informed consent was obtained from each participant before enrollment in the study.

Experimental Measures

Cued Go/NoGo Task. Behavioral inhibition and associated neural correlates were assessed in the presence of alcohol cues using a Cued Go/NoGo task (adapted from Fleming & Bartholow, 2014). All participants completed the task twice, before and after the mindfulness or a control induction. In each task, participants were presented with a series of pictorial stimuli with alcohol and neutral (office supplies) related content. When initially presented following an 800ms fixation cross, each stimulus was surrounded by a white border for a random interval (100, 300, or 500ms). The border subsequently turned either: 1) green, which participants were instructed to respond to by pressing the space bar as quickly as possible, or 2) blue, which participants were instructed to respond to by doing nothing. The Go and NoGo targets remained on the screen for 1000ms following presentation, or until the participant responded. Each task consisted of two blocks, between which participants were able to take a short break if they desired. Within each block, for both alcohol and neutral cues, 25 unique images repeated 4 times each such that participants were presented with 100 alcohol-related pictures and 100 neutral pictures (200 stimuli total in each block, and 2 blocks per Go/NoGo task). In the first block of each task, the borders of the alcohol-related stimuli had an 80% chance of turning green (Go) and a 20% chance of turning blue (NoGo), while the neutral stimuli had an 80% chance of turning blue and a 20% chance of turning green. This flipped in the second block of each Go/NoGo task, such that alcohol-related stimuli had an 80% chance of turning blue and a 20% chance of turning green, while neutral stimuli had an 80% chance of turning green and a 20% chance of

turning blue (see Table 2). In aggregate, 50% of all stimuli presented were alcohol-related, and 50% of all trials were Go trials. This manipulation of cue-targets created eight types of trials such that every possible cue-target combination (alcohol-Go, alcohol-NoGo, neutral-Go, and neutral-NoGo) was presented in both a low and high probability context, allowing effects of probability to be separated from effects of cue type. The order of picture content (alcohol vs. neutral) and trial type (Go vs. NoGo) were completely randomized. All stimuli were separated by an inter-trial interval that lasted 700ms plus the 800ms fixation cross. Each Go/NoGo task took about 20 minutes to complete, and the entire experiment lasted two hours or less for all participants.

Audio condition. Participants were randomly assigned to one of two audio conditions lasting about eight minutes, a mindfulness or control audio clip. The mindfulness audio included a short mindfulness induction with instructions for being mindful of the body and breath, guiding participants to direct their attention towards witnessing the full sensations of breathing without the intention of altering these experiences, and to notice in an accepting manner when their mind's wander and gently return their focus to their breathing ("Mindfulness Meditation of the Body and Breath"; Williams & Penman, 2011). The control audio was a clip of an NPR documentary about scientific discoveries in fruit flies and their nomenclature (All Things Considered, 2010).

Electrophysiological Recording. EEG data were recorded continuously using a BrainVision DC digital EEG amplifier (https://brainvision.com), with 32 Ag/AgCl electrodes in an electrode cap placed using the expanded International

10-20 electrode placement system. Electrooculogram movement was measured using electrodes placed on the lateral canthi and peri-occular electrodes on the superior and inferior orbits, aligned with the pupils. Before data collection was initiated, all impedances were adjusted to within 0-20 kΩ. Data were referenced to a central electrode. EEG data were processed offline using BrainVision Analyzer 2.1.1.327 software (Brain Products GmbH, Gilching, Germany). Data were filtered with an IIR filter with low cutoff of 0.01 Hz and high cutoff of 30 Hz. The data were corrected for eye movement artifacts, using the semi-automatic ocular correction feature of BrainVision. Individual trials with voltages outside a -250 to 250 μV range were excluded from analysis. The data were segmented between 200 ms prior to stimulus onset and 1000 ms post-stimulus onset. After baseline correction over the pre-stimulus interval, segmented data were averaged for each participant in each of the eight conditions of the task. P300 was quantified for each participant individually by identifying each participant's peak amplitude value within an epoch of 300-650ms post Go/NoGo target and deriving the average amplitude from 140 ms surrounding the latency of that peak (i.e., peak ± 70 ms). P300 was examined at electrode Cz. In the control condition, one participant's grand average across all conditions was more than three standard deviations above the mean of all participants, so their data was excluded from analyses.

Self-Report Measures

Alcohol Use Outcomes. Alcohol use was measured using the modified Daily Drinking Questionnaire (DDQ; Collins et al., 1985). Participants were asked

how old they were the first time they drank alcohol, the number of days on which they used alcohol over the past 30-days, and the number of occasions they had binge drank over the past 30-days (i.e., how many times they had consumed five or more standard drinks, if they are male, or four or more standard drinks, if they are female, in a period of two hours or less). The 10-item Alcohol Use Disorder Identification Test (AUDIT; Babor et al., 2016) was also administered, on which individual items are scored on a scale of 0-4, and a summed score above a 16 indicates hazardous use (α = .71). Participants also completed the Escape Questionnaire (Cahalan et al., 1969), used to measure the extent to which individuals consume alcohol to reduce stress and dysphoric feelings. An example item from this scale is “I drink to cheer myself up when I'm in a bad mood.” A summed score of two or higher (out of five) on this scale indicates an escape drinking pattern and is associated with alcohol-related problems (α = .63).

Cannabis Use Outcomes. Cannabis use and related outcomes were measured in all participants who reported using cannabis at least once in the past 30-days using the Marijuana Use Grid (Pearson, Marijuana Outcomes Study Team, & Protective Strategies Study Team 2022). Participants were asked how old they were the first time they used cannabis, and the number of days on which they used cannabis over the past 30-days. If participants reported consuming cannabis at any point over the past 30-days, they were coded into the CAM use group. Participants also completed the 8- item Cannabis Use Disorder Identification Test-Revised (CUDIT-R; Adamson et al., 2010). A summed score of 13 or higher on this scale is indicative of hazardous cannabis use (α = .71).

Craving for Alcohol. Adapted from Waters et al. (2020), participants responded to a single-item craving assessment for alcohol at four time points throughout the neuropsychological testing procedure (at baseline, following the first go/no-go task, following the audio manipulation, and following the second go/no-go task). Participants responded on a 7-point visual analogue scale (1 = N*ot at all*, 7 = *Very much*) to the prompt "Please indicate how much you are craving alcohol RIGHT NOW." Participant's trait craving for alcohol was also assessed, using the 5-item Penn Alcohol Craving Scale (PACS; Flannery et al., 1999). The PACS asks participants to indicate on a 7-point Likert scale the severity of their cravings for alcohol over the past 30-days. An example item from this scale is "At its most severe point, how strong was your craving during this period?". Scores were summed to create a total (α = .84).

State and Trait Mindfulness. The 21-item State Mindfulness Scale (SMS; Tanay & Bernstein, 2013) is measured on a 5-point scale (1 = *Not at all*; 5 = *Very well*), and measures mental (15 items; for example, "I noticed thoughts come and go") and embodied/physical (6 items; for example, "I felt in contact with my body") levels of state mindfulness. This scale has demonstrated strong internal consistency (Tanay & Bernstein, 2013), and construct validity via positive correlations with another measure for state mindfulness, but not trait mindfulness (Cox et al., 2016). Mean scores were used to determine whether greater levels of state mindfulness of mind (α = .86) and body (α = .84), as well as in total (α = .87), were successfully induced in participants in the mindfulness audio condition, with greater scores indicating greater state mindfulness. The Five Facet

Mindfulness Questionnaire (FFMQ; Baer et al., 2006) was administered to measure participant's trait mindfulness characteristics. For this 39-item scale, participants indicate their responses on a 5-point scale (1 = *Never or very rarely true*; 5 = *Very often or always true*). The five facets measured by the scale include acting with awareness (e.g., "I am easily distracted" reverse coded; α = .88), non-judging of inner experience (e.g., "I tell myself I shouldn't be feeling the way I'm feeling" reverse coded; α = .90), non-reactivity to inner experience (e.g., "I watch my feelings without getting lost in them"; α = .86), describing (e.g., "I'm good at finding the words to describe my feelings."; α = .94), and observing (e.g., "When I take a shower or bath, I stay alert to the sensations of water on my body"' α = .72). This scale also demonstrated good internal reliability in the current sample overall (α = .88).

Procedure

Participants began each lab session by reading the informed consent form and having a chance to ask questions about the experiment (see figure 1). After agreeing to participate and confirming that they had participated in binge drinking at least once in the past 30 days (4 and 5 or more drinks in a 2-hour period for females and males, respectively), the EEG cap was placed on their head with the electrodes attached. Participants were led to a Faraday cage and given instructions to try to reduce their movement as much as possible during the task and read the on-screen instructions carefully. Participants then completed the alcohol Go/NoGo tasks, separated by an approximately 8-minute audio clip that delivered one of two conditions that participants were randomly assigned to: a

mindfulness or a control audio clip. At the beginning and end of each Go/NoGo task, participants were asked a single item to assess their craving for both alcohol and cannabis (i.e., two single item assessments at four time points). Following the mindfulness or control audio condition, the state mindfulness scale was administered (Tanay & Bernstein, 2013). After completing the second Go/NoGo task, participants were led out of the Faraday cage, the EEG cap was removed, and they were given a chance to clean up/wash out some of the electrode gel from their hair. When they were done washing up, participants completed the final questionnaire battery that included all other measures from the study. Finally, participants were debriefed and dismissed.

Analytic Plan

All statistical analyses were conducted using SPSS software package (version 27.0). We first performed between-group comparisons on demographic variables and other measures relevant to the study to ensure groups did not differ on important variables (see table 1). Because of the pre- and post-test design, it would not make sense to assess the factors of audio manipulation (mindfulness vs. control) and task (1 vs. 2) within the same analysis, due to the fact that the manipulation occurred after task 1 and an interaction among audio manipulation group and task number would not be interpretable. Additionally, adding task as a factor would have left us with a six-way ANOVA, which seemed untenable considering the marginal analytic benefits gained by including it as a factor. Therefore, we did not include task as a factor in any of the analyses and assessed all of our hypotheses within tasks 1 and 2 separately. Hypotheses were

tested as follows: 1) to test if P300 amplitudes differed across conditions, we conducted in task 1 a three-way 2x2x2 Repeated Measures (RM) analysis of variance (ANOVA) with the within-subjects factors of block (1 vs. 2), target (Go vs. NoGo), and cue (alcohol vs. neutral), 2) in task 1 only, we examined whether craving for alcohol moderated the effects expected in hypothesis 2 using a four-way 2x2x2x2 RM ANCOVA with the within-subjects factors of block (1 vs. 2), target (Go vs. NoGo), and cue (alcohol vs. neutral), and the continuous predictor of craving for alcohol (C2, assessed immediately following the first task), 3) to examine whether the mindfulness audio reduced craving, we conducted a 2-way mixed ANOVA with the within-subjects factor of craving (immediately before vs. after the audio manipulation) and the between-subjects factor of audio manipulation (mindfulness vs. control), 4) to examine whether the brief mindfulness induction impacted P300 amplitudes in task 2 only, we conducted a four-way mixed ANOVA with the within-subjects factors of block (1 vs. 2), target (Go vs. NoGo), and cue (alcohol vs. neutral), and the between-subjects factor of audio manipulation (mindfulness vs. control), and 5) to test whether the audio manipulation and alcohol craving interacted to moderate the hypothesized three-way interaction from hypothesis 2 in task 2 only, we ran a five-way 2x2x2x2 mixed ANCOVA with within-subjects factors block (1 vs. 2), target (Go vs. NoGo), cue (alcohol vs. neutral), and craving (continuous predictor, C3), and between-subjects factor of audio manipulation (mindfulness vs. control).

For our exploratory research questions, to assess if differences in alcohol craving existed among alcohol only compared to CAM use status over the past

30-days, we conducted a two-way 2x2 mixed ANOVA with the within-subjects factor of craving for alcohol (C1 vs. C2) and between-subjects factor of CAM (CAM vs. No CAM). Next, to examine if baseline (task 1) P300 ERP amplitudes in in the various conditions of the task differed among individuals who report alcohol only vs. CAM, we conducted a four-way 2x2x2x2 mixed ANOVA with the within-subjects variables of block (1 vs. 2), target (Go vs. NoGo), and cue (alcohol vs. neutral), and the between-subjects factor of CAM (CAM vs. No CAM). For all analyses statistical significance was determined at $p < .05$. However, given our small sample size, we also interpreted theoretically relevant findings (including interactions) that had medium-large effect sizes (η^2 of .01 = small, .06 = medium, .14 = large; Richardson, 2011), even if results were statistically non-significant.

Results

Randomization and Manipulation Checks

To determine whether our randomization of participants resulted in audio manipulation groups (mindfulness vs. control) without significant differences between them, between-group comparisons were conducted on demographic variables and other measures relevant to the study (see Table 1 for sample statistics broken down in total and by audio manipulation group). The groups did not differ on their compositions for any demographic variables. They also did not significantly differ on most other variables related to alcohol use, cannabis use, alcohol craving, and mindfulness. However, they did differ significantly on two variables: past 30-day alcohol use frequency (t [28] = 3.09, p = .005), and past

30-day binge drinking occasions (t [28] = 2.54, p = .019). Although significant, adding these variables as covariates would diminish power for finding statistically significant effects and given our already small sample size, we chose to run the analyses without controlling for the effects of either. Additionally, while we expected to find a significant difference between the mindfulness and control groups on the State Mindfulness Scale (especially the body subscale), we did not find a statistically significant difference for any of the subscales (total: t[28] = -1.44, p = .161; d = 0.50; Mind: t[28] = -1.09, p = .285; d = 0.54; Body: t[28] = -1.32, p = .198; d = 0.81). While not statistically significant, effect sizes ranged from medium for the total scale (Mindfulness M = 3.6, SD = 0.5; Control M = 3.4, SD = 0.5) and mind subscale (Mindfulness M = 3.7, SD = 0.6; Control M = 3.5, SD = 0.5), to large for the body subscale (Mindfulness M = 3.5, SD = 0.7; Control M = 3.1, SD = 0.9), with higher scores reported within the mindfulness conditions. These indicate that the audio manipulation is having a medium-large effect on measures of state mindfulness, but our small sample size reduced power to detect statistically significant differences.

Primary Analyses

Hypothesis 1 (see Table 3). To test if a three-way interaction on P300 amplitudes existed within task 1, block (1 vs. 2), target (Go vs. NoGo), and cue (Alcohol vs. Neutral), we performed a three-way 2x2x2 RM ANOVA on P300 ERP responses. We found a significant main effect of target, F(1, 29) = 68.60, p < .001, η^2 = .70, such that Go trials (M = 5.87; SE = 0.46) were associated with larger P300 amplitudes compared to NoGo trials (M = 2.99; SE = 0.35). This

effect was qualified by a three-way interaction, $F(1, 29) = 7.95$, $p = .009$, $\eta^2 = .22$. We broke the interaction down by block. In block 1, found an interaction between cue and target trending towards significance with a medium-large effect size, $F(1, 29) = 4.03$, $p = .054$, $\eta^2 = .12$. Post-hoc analyses revealed that P300 amplitudes in the Go condition were not statistically different in neutral ($M = 5.97$; $SE = 0.47$) compared to alcohol ($M = 5.69$; $SE = 0.49$) stimuli, $t(29) = -0.60$, $p = .555$, while in the NoGo condition alcohol ($M = 3.50$; $SE = 0.57$) stimuli approached significance with larger P300 amplitudes than neutral ($M = 2.40$; $SE = 0.31$), $t(29) = 2.00$, $p = .055$. In block 2, we found an interaction between cue and target that was significant, $F(1, 29) = 6.43$, $p = .017$, $\eta^2 = .18$. This interaction occurred such that P300 amplitudes in the Go condition were significantly larger for alcohol ($M = 6.51$; $SE = 0.69$) compared to neutral ($M = 5.29$; $SE = 0.51$), $t(29) = 2.67$, $p = .012$, but in the NoGo condition neutral ($M = 3.47$; $SD = 3.2$) and alcohol ($M = 2.6$; $SD = 2.35$) stimuli did not differ significantly, $t(29) = -1.61$, $p = .118$.

Hypothesis 2 (see Table 4). To test if the three-way interaction from hypothesis 2 (task 1 only) is moderated by craving for alcohol, we ran a four-way 2x2x2 RM ANCOVA with within-subjects variables block (1 vs. 2), target (Go vs. NoGo), and cue (Alcohol vs. Neutral), and the continuous predictor of craving at C2. We focused on effects including the continuous factor of craving only, and observed a non-significant three-way cue by target by craving interaction, $F(1, 28) = 2.94$, $p = .097$, $\eta^2 = .10$. Because we observed a medium-large effect size, we broke the interaction down by target. In Go targets, there was not a significant interaction between drug cue and craving at C2, $F(1, 28) = 1.66$, $p = .208$, $\eta^2 =$

.06. In NoGo targets, there was not a significant interaction between drug cue and craving at C2, $F(1, 28) = 1.720$, $p = .20$, $\eta^2 = .06$.

Hypothesis 3 (see Table 5). To test if the mindfulness audio reduced craving, we conducted a two-way 2x2 mixed ANOVA with the within-subjects factor time of craving immediately before and after the audio manipulation (C2 vs. C3) and the between-subjects factor of audio manipulation (mindfulness vs. control). There was a significant main effect of time of craving, $F(1, 28) = 9.14$, $p = .005$, $\eta^2 = .25$, such that craving at C3 ($M = 1.47$; $SD = 0.16$) was significantly lower than craving at C2 ($M = 1.89$; $SD = 0.21$) regardless of audio manipulation condition. The craving by audio manipulation interaction was not significant, but showed a medium effect size, $F(1, 28) = 2.19$, $p = .15$, $\eta^2 = .07$. The interaction occurred such that the decrease in craving across time points C2→C3 in the mindfulness condition was significant with a large effect size ($M_{Difference} = 0.63$; $t(15) = 2.61$, $p = .02$; $d = 0.96$) and was greater than the decrease in the control condition with a small-medium effect size ($M_{Difference} = 0.21$; $t(13) = 1.88$, $p = .082$; $d = 0.46$).

Hypothesis 4 (see Table 6). To test if in task 2 only, a three-way interaction between the within-subjects factors of block (1 vs. 2), target (Go vs. NoGo), and cue (Alcohol vs. Neutral) was moderated by the between-subjects factor of audio manipulation (mindfulness vs. control), we ran a four-way 2x2x2x2 mixed ANOVA. We found a main effect of target, $F(1, 28) = 32.03$, $p < .001$, $\eta^2 = .53$, such that Go targets ($M = 5.27$; $SE = 0.44$) were significantly greater than NoGo targets ($M = 29.48$; $SE = 1.86$). We also found a non-significant three-way

interaction between target, cue, and audio manipulation, $F(1, 28) = 2.12$, $p = .156$, $\eta^2 = .07$, which we chose to interpret due to the medium effect size. Breaking the interaction down by target, we did not find any significant interaction between cue and audio manipulation for Go, $F(1, 28) = 0.87$, $p = .36$, $\eta^2 = .03$, and NoGo targets, $F(1, 28) = 1.72$, $p = .26$, $\eta^2 = .05$. We did not observe any other statistically significant effects of theoretical interest (effect sizes were also small).

Hypothesis 5 (see Table 7). To test if in task 2 only, a three-way interaction between the within-subjects factors of block (1 vs. 2), target (Go vs. NoGo), and cue (Alcohol vs. Neutral) was moderated by the between-subjects factor of audio manipulation (mindfulness vs. control) and the continuous predictor of alcohol craving at timepoint C3, we ran a five-way 2x2x2x2 mixed ANCOVA. We did not observe any statistically significant effects of theoretical interest (effect sizes were also small).

Exploratory Analyses

Exploratory analyses were conducted in task 1 to test if craving for alcohol differed based on CAM use. We conducted a 2x2 mixed ANOVA (see Table 8) with the within-subject factor of craving (C1 vs. C2) and the between-subjects factor of CAM use over the past 30-days (No CAM use vs. CAM use). We observed a main effect of time on craving, $F(1, 28) = 6.00$, $p = .021$, $\eta^2 = .18$, such that craving at C2 ($M = 1.93$; $SE = 0.21$) was significantly greater than C1 ($M = 1.56$; $SE = 0.17$). We did not observe main effects of CAM group nor an interaction between time of craving and CAM.

To test if P300 amplitudes differed under any conditions of the second task based on CAM use status over the past 30-days, we ran a four-way 2x2x2x2 mixed ANOVA (see Table 9) with the within-subjects factors of block (1 vs. 2), target (Go vs. NoGo), and cue (Alcohol vs. Neutral), and between-subjects factor of CAM use over the past 30-days (No CAM use vs. CAM use). We found a significant main effect of target, $F(1, 28) = 72.21$, $p < .001$, $\eta^2 = .72$, such that Go ($M = 5.96$; $SE = 0.47$) were significantly greater than NoGo targets ($M = 2.99$; $SE = 0.36$). We also found a non-significant three-way interaction between cue, target, and CAM use status, $F(1, 28) = 1.75$, $p = .197$, $\eta^2 = .06$, which we decided to break down by target due to the medium effect size. For both Go and NoGo targets, we did not observe any significant interactions, though for NoGo we did find a greater than medium effect size for the interaction between cue and CAM use status, $F(1, 28) = 2.11$, $p = .157$, $\eta^2 = .07$. Post-hoc independent samples t-tests indicated P300 amplitudes did not significantly differ between the CAM vs. no CAM groups for both alcohol, $t(28) = 0.53$, $p = .599$, and neutral cues, $t(28) = -0.52$, $p = .608$.

Discussion

P300 ERPs have been posited as a potential biomarker for response inhibition deficits associated with substance use problems and addiction across different drugs of abuse (Zhang et al., 2021), but findings in the literature have been inconsistent for alcohol. The present study recruited a non-clinical sample of binge drinking college students and aimed to examine potential differences in P300 ERPs to drug-related and control stimuli within two Cued Go/NoGo tasks.

We aimed to examine whether neural activity to these cues differed between participants who were assigned to listen to either a mindfulness or control audio recording. Further, we tested whether P300 activity would be related to levels of craving for alcohol, and whether participants concurrently used alcohol and marijuana (CAM) compared to just alcohol over the past 30-days.

In our baseline task that occurred before the audio manipulation, we hypothesized that P300 amplitude would differ based on the probability of Go versus NoGo trials in each block, whether the target was alcohol-related or neutral, and whether the trial was a Go or NoGo trial. Specifically, we expected that this interaction would be driven by significantly larger P300 amplitudes in block 2 (conflict condition; 20% alcohol-Go, 80% alcohol-NoGo, 20% neutral-NoGo, 80% neutral-Go) alcohol-NoGo conditions compared to neutral-NoGo. Our hypothesis was partially supported such that we observed a three-way interaction that was driven by greater P300 amplitudes for alcohol compared to neutral cues. Our results partially align with previous literature indicating that alcohol cues are associated with greater P300 amplitudes than neutral cues, though in the present study this only occurred in the block 1 NoGo and block 2 Go conditions (Czapla et al., 2015; Fleming & Bartholow, 2014; Zhang et al., 2021). These results are promising in that they reflect previous research findings that P300-related processing is greater for alcohol compared to neutral cues under specific conditions of a Go/NoGo task, but it remains unclear why this difference was only observed in block 1 NoGo and block 2 Go trials. This may be a reflection of neural processing related to a relatively novel drug stimulus, given

that block 1 NoGo and block 2 Go trials each represent 20% of the cues presented for their respective block. These results may also reflect larger problems in the current sample, specifically, that we chose to only examine P300 at the electrode Cz, and our small sample size. We also tested to see if P300 amplitudes differed under any conditions of the second task based on CAM use status over the past 30-days, and found no theoretically interesting effects.

Taking it a step further, we tested whether this three-way interaction would be moderated by craving for alcohol. There could be several explanations for why we did not observe any theoretically interesting effects in this analysis, with the most likely being that craving for alcohol may simply not be involved in response inhibition related P300 processing in binge drinking college students with low craving. Given the low levels of craving observed at each of the four single-item assessments (mean range across time points = 1.4-1.9, on a scale of 1-7), our participants may not be experiencing clinically significant craving (for example, Stein et al., 2018, reports much higher craving in AUD patients compared to controls, with M = 8.70; SD = 5.90 and M = 2.40; SD = 1.84, respectively) for alcohol that might influence neural measures of response inhibition in the same ways it would for clinical populations with high craving for alcohol. This seems likely given that previous research demonstrated that craving is an important factor related to response inhibition (Kreusch et al., 2017; Stein et al., 2018) whereas in this study, significant differences in craving between participants at time point C2 were not found.

Next, we hypothesized that craving scores immediately prior to and after

the audio manipulation would be attenuated by the brief mindfulness induction relative to the control group. We observed a non-significant interaction between time of craving and audio condition, but with a medium effect size. Post-hoc analyses revealed that while craving significantly decreased from C2 to C3 for both audio conditions, in the mindfulness group the decrease showed a larger effect size. These results add to the body of literature supporting positive effects of mindfulness on alcohol craving (Bowen et al., 2009; Brewer et al., 2012; Witkiewitz & Bowen, 2010). Additionally, the present results support the idea that even in college students with low baseline levels of craving for alcohol, it may be useful to incorporate a brief mindfulness induction for reducing craving and improving alcohol-related outcomes. Given the ease with which brief mindfulness inductions can be administered by treatment providers and digested by participants in a short time, future research should utilize longitudinal research designs to examine alcohol-related outcomes associated with brief mindfulness inductions and related mechanisms over time.

In task 2, after the audio manipulation, we hypothesized a four-way interaction would exist between block, target, cue, and audio condition, on P300 amplitudes, such that in the block 2 alcohol-NoGo conditions compared to neutral-NoGo, there would be a larger difference in participants assigned to the control compared to mindfulness condition. We observed a non-significant three-way interaction between target, cue, and audio manipulation with a medium effect size. While post-hoc analyses did not indicate any significant differences among the audio manipulation groups or task conditions, this is an interesting

interaction to observe with such a small sample size. In an analysis with more statistical power, we would expect to find differences in P300 amplitudes between mindfulness and control groups on alcohol-NoGo trials, meaning we would expect the mindfulness audio would be associated with reduced P300s relative to controls on inhibition- and drug-related trials. Future research should examine whether this hypothesis is true, and in turn identify whether a brief mindfulness induction could be used to reduce deficits in alcohol-related inhibitive processing. Finally, we hypothesized that this four-way interaction would be moderated by craving for alcohol, but found no significant results of theoretical interest. These inconsistent results may again be a product of the small sample size and singular electrode at which P300 was measured.

A study recently demonstrated that exposure to combined cigarette and alcohol cues (Motschman & Tiffany, 2021) elicited greater craving and drug seeking responses compared to cues with only one type of drug among individuals who used both substances. Therefore, in an exploratory analysis on task 1, we also wanted to test if craving for alcohol differed based on whether individuals had used cannabis and alcohol over the past 30 days compared to participants who had only used alcohol. While participants were not exposed to dual cues nor any cues related to cannabis, we wondered whether individuals who use alcohol and cannabis concurrently might differ in their craving for alcohol only within the same task, compared to individuals who only use alcohol. We observed null results for this analysis, which may indicate that alcohol and cannabis craving are not closely related. Alternatively, because our sample did

not consist of individuals with clinically relevant symptoms of either alcohol or cannabis dependence and craving, it would be worthwhile to examine interactions between craving for alcohol and cannabis among individuals who show greater levels of craving. Future research may examine polysubstance use and its implications for other important drug use-related constructs like craving across drugs of abuse. Future work may also benefit from a dual cue approach whereby cues for alcohol and cannabis are presented together to examine how this might influence craving for either substance.

Limitations

This study should be considered in light of several limitations. First, as previously mentioned, the sample sizes used for analyses were small and, while they allowed us to probe for effects within the task by interpreting *p*-values and effect sizes, do not provide adequate statistical power to comprehensively test our proposed hypotheses. Additionally, the total sample was not very diverse, with the majority of participants identifying as White females, which may limit the generalizability of our results. Participants also reported very low levels of craving which may have influenced our results on tests used to examine the effects of craving for alcohol on P300 ERPs within the study conditions, and did not differ significantly on measures of state mindfulness, despite large effect sizes.

Conclusions

P300 ERPs associated with response inhibition show potential for advancing the identification, understanding, and treatment of addictive behaviors related to alcohol and other drugs. Our results showing that P300-related

processing is greater for alcohol compared to neutral cues under specific conditions of a Go/NoGo task are promising because they partially reflect previous research, but the fact we only observed these effects in block 1 NoGo and block 2 Go trials is puzzling. Additionally, it is likely that low levels of craving observed in the current sample underlies our failure to identify significant differences related to craving in any of the task conditions. Going forward, research should examine in larger samples how craving may interact with inhibition-related processing in populations with more craving and craving variability than was found in the present sample. With regard to mindfulness, the present results support the idea that even in college students with low craving for alcohol, it may be useful to incorporate interventions that utilize brief mindfulness inductions for improving alcohol-related outcomes in this high-risk group. Mechanisms related to brief mindfulness intervention associations with response inhibition should be examined in the context of longitudinal and experimental studies to understand how these brief interventions may confer positive effects.

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Table 1
Demographics and Participant Information

	Total (N = 30)	Mindfulness (N = 16)	Control (N = 14)	t or χ^2 (Mindfulness vs. Control)	p
Gender	n (%)	n (%)	n (%)	$\chi^2 = 2.07$	p = .151
Female	21 (70.0)	13 (81.3)	8 (57.1)		
Male	9 (30.0)	3 (18.8)	6 (42.9)		
Age	M (SD)	M (SD)	M (SD)		
	19.07 (0.91)	18.94 (0.68)	19.21 (1.12)	t = 0.83	p = .414
Race	n (%)	n (%)	n (%)	$\chi^2 = 0.02$	p = .886
White	26 (86.7)	14 (87.5)	12 (85.7)		
Asian	4 (13.3)	2 (12.5)	2 (14.3)		
Education[a]	n (%)	n (%)	n (%)		
Freshman	19 (63.3)	12 (75.0)	7 (50.0)	$\chi^2 = 2.01$	p = .156
Sophomore	9 (30.0)	4 (25.0)	5 (35.7)		
Junior	0 (0)	0 (0)	0 (0)		
Senior	2 (6.7)	0 (0)	2 (14.3)		
Alcohol Use	M (SD)	M (SD)	M (SD)		
Past 30-day Use Frequency	7.50 (3.24)	6.00 (2.50)	9.21 (3.19)	**t = 3.09**	**p = .005***
Past 30-day Binge Drinking Occasions	3.50 (2.30)	2.56 (1.59)	4.57 (2.56)	**t = 2.54**	**p = .019***
Age of onset	15.30 (2.63)	15.50 (1.83)	15.07 (3.39)	t = -0.44	p = .664
AUDIT	12.90 (4.93)	12.38 (4.90)	13.50 (5.08)	t = 0.62	p = .542
Escape drinking	1.47 (1.22)	1.19 (0.91)	1.79 (1.48)	t = 1.31	p = .203
Number reporting cannabis use	n (%)	n (%)	n (%)	$\chi^2 = 0.09$	p = .765
	18 (60.0)	10 (62.5)	8 (57.1)		
[b]Cannabis Use	M (SD)	M (SD)	M (SD)		
Past 30-day Use Frequency	5.17 (4.55)	4.00 (2.83)	6.63 (5.98)	t = 1.23	p = .235

Age of onset	16.86 (1.11)	17.13 (1.19)	16.54 (0.97)	t = -1.44	p = .162
CUDIT-R	6.55 (4.06)	5.50 (4.30)	7.88 (3.56)	t = 1.25	p = .228
Number reporting simultaneous alcohol/cannabis use	n (%) 15 (50.0)	n (%) 8 (50.0)	n (%) 7 (50.0)	$\chi^2 = 0.00$	p = 1.00
[b]Simultaneous use of Alcohol and Cannabis	M (SD)	M (SD)	M (SD)		
Past 30-day simultaneous use days	3.60 (3.09)	3.4 (3.2)	3.9 (3.2)	t = 0.29	p = .775
Mindfulness	M (SD)	M (SD)	M (SD)		
FFMQ Total	3.25 (0.41)	3.25 (0.43)	3.25 (0.39)	t = 0.02	p = .984
FFMQ Observing	3.50 (0.58)	3.54 (0.51)	3.45 (0.67)	t = -0.43	p = .672
FFMQ Describing	3.52 (0.83)	3.51 (0.85)	3.53 (0.83)	t = 0.06	p = .951
FFMQ Acting with Awareness	3.09 (0.68)	3.16 (0.61)	3.01 (0.78)	t = -0.58	p = .566
FFMQ Nonjudging of inner experience	3.09 (0.77)	3.09 (0.71)	3.09 (0.87)	t = 0.01	p = .991
FFMQ Nonreactivity to inner experience	3.05 (0.66)	2.93 (0.64)	3.19 (0.67)	t = 1.11	p = .276
SMS Total	3.50 (0.51)	3.62 (0.54)	3.35 (0.46)	t = -1.44	p = .161
SMS Mind	3.57 (0.54)	3.66 (0.60)	3.45 (0.46)	t = -1.09	p = .285
SMS Body	3.32 (0.82)	3.50 (0.69)	3.11 (0.93)	t = -1.32	p = .198
Craving	M (SD)	M (SD)	M (SD)		
Penn Alcohol Craving Scale (PACS)	7.83 (4.02)	7.38 (3.32)	8.36 (4.77)	t = 0.66	p = .514
Single item alcohol craving: C1	1.53 (0.90)	1.56 (0.89)	1.50 (0.94)	t = -0.19	p = .853
Single item alcohol craving: C2	1.90 (1.13)	2.00 (1.16)	1.79 (1.12)	t = -0.51	p = .611
Single item alcohol craving: C3	1.47 (0.86)	1.38 (0.62)	1.57 (1.09)	t = 0.62	p = .542
Single item alcohol craving: C4	1.63 (0.96)	1.50 (0.89)	1.79 (1.05)	t = 0.81	p = .428

Note. [a] A dichotomous variable for Education was constructed for the Chi-squared difference test: Freshman vs. Not Freshman.
[b]Statistics on continuous cannabis and simultaneous cannabis/alcohol use variables were examined only in those who reported use.
AUDIT = Alcohol Use Identification Disorder; CUDIT-R = Cannabis Use Disorder Identification Test-Revised FFMQ = Five Facet Mindfulness Questionnaire; SMS = State Mindfulness Scale.

Table 2
Target/Cue Probabilities as a Function of Block

	Block 1		Block 2	
Cue Type	Go	NoGo	Go	NoGo
Alcohol	.80	.20	.20	.80
Neutral	.20	.80	.80	.20

Note. Total trials = 400 (200/block).

Table 3
Task 1 P300 amplitudes as a function of within-subjects factors block, cue, and target

Source	SS	df	MS	*F*	*p*	η^2
Block (1 vs. 2)	0.354	1	0.354	0.07	.800	0.00
Cue (Alcohol vs. Neutral)	5.09	1	5.09	2.54	.122	0.08
Target (Go vs. NoGo)	495.97	1	495.97	68.60	< .001*	0.70
Block*Cue	0.83	1	0.83	0.17	.680	0.006
Block*Target	0.01	1	0.01	0.00	.967	0.00
Cue*Target	1.96	1	1.96	0.66	.425	0.02
Block*Cue*Target	45.58	1	45.58	7.95	.009*	0.22

Note. * indicates a p-value of statistical significance ($p < .05$).

Table 4

Task 1 P300 amplitudes as a function of within-subjects factors block, cue, and target, and the continuous predictor craving at C2

Within-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
Block (1 vs. 2)	6.01	1	6.01	1.11	.300	0.04
Block*C2	6.20	1	6.20	1.15	.293	0.04
Cue (Alcohol vs. Neutral)	1.39	1	1.39	0.67	.421	0.02
Cue*C2	0.00	1	0.00	0.00	.972	0.00
Target (Go vs. NoGo)	177.43	1	177.43	24.39	< .001*	0.47
Target*C2	6.00	1	6.00	0.82	.372	0.03
Block*Cue	2.00	1	2.00	0.41	.529	0.01
Block*Cue*C2	1.22	1	1.22	0.25	.622	0.01
Block*Target	4.04	1	4.04	1.15	.293	0.04
Block*Target*C2	5.20	1	5.20	1.48	.234	0.05
Cue*Target	10.14	1	10.14	3.62	.067	0.12
Cue*Target*C2	8.24	1	8.24	2.94	.097	0.10
Block*Cue*Target	25.34	1	25.34	4.36	.046*	0.14
Block*Cue*Target*C2	3.59	1	3.59	0.62	.438	0.02
Between-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
C2 (Craving at time 2)	55.07	1	55.07	1.73	.199	0.06

Note. * indicates a p-value of statistical significance ($p < .05$).

Table 5

Alcohol craving immediately before (C2) and after (C3) audio manipulation, as a function of audio group assignment

Within-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
Craving time (C2 vs. C3)	2.63	1	2.63	9.14	.005*	0.25
Craving*Audio	0.63	1	0.63	2.19	.150	0.07
Between-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
Audio (Mindfulness vs. control)	0.00	1	0.00	0.00	.979	0.00

Note. * indicates a p-value of statistical significance ($p < .05$).

Table 6

Task 2 P300 amplitudes as a function of within-subjects factors block, cue, target, and between-subjects factor audio group assignment

Within-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
Block (1 vs. 2)	0.27	1	0.27	0.03	.855	0.001
Block*Audio	25.42	1	25.42	3.12	.085	0.102
Cue (Alcohol vs. Neutral)	17.19	1	17.19	2.29	.141	0.08
Cue*Audio	6.94	1	6.94	0.93	.344	0.03
Target (Go vs. NoGo)	322.80	1	322.80	32.03	< .001*	0.53
Target*Audio	58.88	1	58.88	5.84	.022*	0.17
Block*Cue	5.01	1	5.01	0.998	.326	0.03
Block*Cue*Audio	6.13	1	6.13	1.22	.278	0.04
Block*Target	6.43	1	6.43	1.30	.265	0.04
Block*Target*Audio	0.14	1	0.14	0.03	.868	0.00
Cue*Target	0.76	1	0.76	0.06	.812	0.00
Cue*Target*Audio	27.82	1	27.82	2.12	.156	0.07
Block*Cue*Target	3.47	1	3.47	0.69	.415	0.02
Block*Cue*Target*Audio	1.82	1	1.82	0.36	.554	0.01
Between-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
Audio (Mindfulness vs. control)	0.39	1	0.39	0.01	.928	0.00

Note. * indicates a p-value of statistical significance ($p < .05$).

Table 7

Task 2 P300 amplitudes as a function of within-subjects factors block, cue, target, between-subjects factor audio group assignment, and continuous predictor craving at C3

Within-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
Block (1 vs. 2)	0.10	1	0.10	0.01	.915	0.00
Block*C3	0.00	1	0.00	0.00	.983	0.00
Block*Audio	25.15	1	25.15	3.05	.092	0.10
Cue (Alcohol vs. Neutral)	16.61	1	16.61	2.19	.150	0.08
Cue*C3	5.40	1	5.40	0.71	.406	0.03
Cue*Audio	8.32	1	8.32	1.10	.304	0.04
Target (Go vs. NoGo)	81.07	1	81.07	7.76	.010*	0.22
Target*C3	0.01	1	0.01	0.00	.975	0.00
Target*Audio	58.27	1	58.27	5.58	.026*	0.17
Block*Cue	5.05	1	5.05	0.98	.330	0.04
Block*Cue*C3	1.72	1	1.72	0.33	.568	0.01
Block*Cue*Audio	5.33	1	5.33	1.04	.318	0.04
Block*Target	8.08	1	8.08	1.61	.215	0.06
Block*Target*C3	3.33	1	3.33	0.66	.422	0.02
Block*Target*Audio	0.34	1	0.34	0.07	.796	0.00
Cue*Target	1.34	1	1.34	0.10	.756	0.00
Cue*Target*C3	0.70	1	0.70	0.05	.822	0.00
Cue*Target*Audio	28.47	1	28.47	2.10	.159	0.07
Block*Cue*Target	1.34	1	1.34	0.26	.618	0.01
Block*Cue*Target*C3	0.07	1	0.07	0.01	.908	0.00
Block*Cue*Target*Audio	1.72	1	1.72	0.33	.573	0.01
Between-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
C3 (Craving at time 3)	12.30	1	12.30	0.26	.617	0.01
Audio (Mindfulness vs. control)	1.06	1	1.06	0.02	.883	0.00

Note. * indicates a p-value of statistical significance ($p < .05$).

Table 8

Task 1 craving (C1 vs. C2) as a function of between-subjects factor CAM use status

Within-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
Craving time (C1 vs. C2)	2.03	1	2.03	6.00	.021*	0.18
Craving*CAM	0.03	1	0.03	0.07	.788	0.00
Between-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
CAM (Yes vs. No)	1.00	1	1.00	0.57	.46	0.02

Note. * indicates a p-value of statistical significance ($p < .05$).

Table 9

Task 1 P300 amplitudes as a function of within-subjects factors block, cue, target, and between-subjects factor CAM use status

Within-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
Block (1 vs. 2)	1.33	1	1.33	0.25	.622	0.01
Block*CAM	8.07	1	8.07	1.52	.228	0.05
Cue (Alcohol vs. Neutral)	5.66	1	5.66	2.76	.108	0.09
Cue*CAM	0.72	1	0.72	0.35	.558	0.01
Target (Go vs. NoGo)	507.84	1	507.84	72.21	< .001*	0.72
Target*CAM	12.77	1	12.77	1.82	.189	0.06
Block*Cue	0.79	1	0.79	0.16	.692	0.01
Block*Cue*CAM	0.00	1	0.00	0.00	.994	0.00
Block*Target	0.55	1	0.55	0.18	.677	0.01
Block*Target*CAM	16.78	1	16.78	5.40	.028*	0.16
Cue*Target	0.85	1	0.85	0.29	.594	0.01
Cue*Target*CAM	5.08	1	5.08	1.75	.197	0.06
Block*Cue*Target	50.72	1	50.72	8.88	.006*	0.24
Block*Cue*Target*CAM	6.41	1	6.41	1.12	.299	0.04
Between-subjects factors						
Source	SS	df	MS	*F*	*p*	η^2
CAM (CAM vs. no CAM)	13.05	1	13.05	0.39	.536	0.01

Note. * indicates a p-value of statistical significance ($p < .05$).

Figure 1.

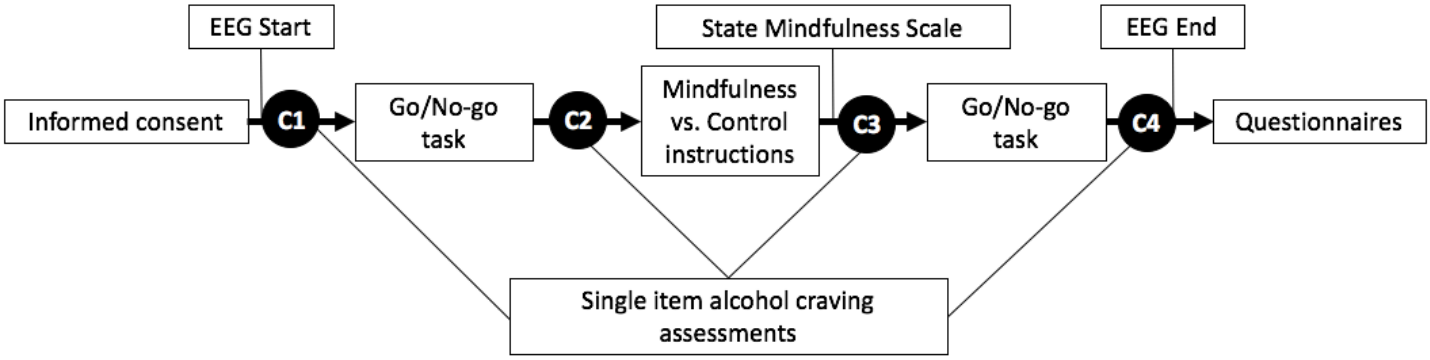

Figure 1. Experimental timeline.