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The Reward Positivity in Individuals with Alcohol Use Disorder

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BY

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ABSTRACT

The Reward Positivity (RewP) is a positive deflection in the EEG after receiving a reward. Recent evidence suggests that the RewP is modulated by both reward probability aside from affective liking. Here we examined the sensitivity of the RewP to affective and alcohol images in individuals with alcohol use disorder (AUD). We recruited 55 participants (AUD =28, Control= 27). Participants completed an image rating task and a reinforcement learning task with picture feedback (puppy or alcohol images over a green or red screen). Although there was no between group differences in puppy image ratings, there was a significant group difference in alcohol images. Within AUD group, there was significant positive correlation between AUDIT score and RewP amplitudes, signifying the influence of increase in alcohol consumption on the magnitude of RewP. Modulation of this signal by alcohol specific cues is in line with general "liking" related trends observed in AUD sample.

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Introduction

Alcohol Use Disorder

The *Diagnostic and Statistical Manual of Mental Disorders-5th edition, DSM-5;* defines AUD as the impaired ability to stop or control alcohol use despite adverse health, social, or occupational consequences. According to the National Institute on Alcohol Abuse and Alcoholism (NIAAA), more than 17 million people in America either misuse or are dependent on alcohol which burdens the society with an estimate of over $180 billion annually. Alcohol results in approximately 3.3 million deaths yearly (WHO, 2014). Since AUD is such a dominant public health concern, numerous researchers have and continue to attempt to study the various aspects of it such as genetic components, pharmacological components, medication, reward processing etc.

A primary source of problem for people with AUD is the stimulation of the brain's reward (pleasure) system. The brains of human beings have advanced with respect to reward system such that they are more prone to repeat behaviors with rewarding outcomes without necessarily thinking about it (Ostafin et al., 2008). AUD is associated with stimulus-response conditioned behaviors (Elkins et al., 2017). Looking at images of alcoholic beverages, people consuming it, associated places like image of a bar etc. can make people with AUD feel a sense of mild pleasure or satisfaction. Thus, AUD is associated with increased liking of the image, taste and feel of alcohol-containing drinks (Tapert et al., 2004). A vital objective of the scientific study of alcohol misuse is to examine the neural underpinnings related with the abnormal control due to alcohol consumption and reward processing ability in individuals with AUD (NIAAA 2007b).

Some researchers have argued that AUD can be charted in terms of a dampened response to reward. For example, the reward deficiency hypothesis in the study by (Blum et al,1996) suggests that individuals who demonstrate persistent hypo reactivity to rewards are more likely to be involved in risky alcoholic behaviors to reimburse for deficient natural reinforcement and underactive dopamine neurotransmission. It has been shown in both of human and rodent research that exposure to increased alcohol consumption leads to neuroadaptations in brain which has potential negative affect and blunted reactivity to non-alcohol related rewards (Koob, 2013). However, a simultaneous varying literature suggests that AUD is stimulated with increased reward responsiveness. In other words, an increased reward responsiveness is associated with an increased alcohol consumption in non-clinical population and a risk of AUD development with early onset drinking (Franken & Muris, 2006; Loxton & Dawe, 2001).

Reward Processing

The reward system (mesocorticolimbic circuit) is an assembly of neural circuits that are responsible for incentive salience (incentive and wanting, desire or crave for a reward), associative learning (positive reinforcement and classical conditioning) and positively valanced emotions particularly, the ones involving pleasure as the outcome (happiness, exhilaration, ecstasy) (Schultz, 2015). Reward cognition serves to be attracted and motivated by positively reinforcing stimuli. Accordingly, the neural representations of both reward and reinforcement are of important significance to understand normal brain-behavior interactions and the pathophysiology of disorders such as depression and AUD (Gilpin & Koob, 2008).

Positive reinforcement is important in understanding the extent and significance of alcohol-based cues for individuals with AUD. Exposure to alcohol-induced cues can stimulate variations in neural circuits that regulate liking, stress, reward, and arousal, all of which are likely to shape motivated behaviors (Gilpin et al. 2008a). The disciplines of neuroscience, neurophysiology, behavior, and subjective behavior support the clear demarcation found in the existing literature on reward, a classic division that has been drawn separating the hedonic influence of reward attainment and the anticipation phase associated with it (Lewis and June 1990). Often this has been named, "wanting vs liking". There are multiple distinguishable aspects of reward anticipation, for example, at the individual level, reward anticipation can be due to wanting (desiring and urging) and as excitement and eagerness (Berridge, 2012). As the behavioral aspect is explored, reward anticipation is reflected as behavior directed towards accomplishing a target or goal. When rewards are at stake, varying aspects of cognitive, behavioral, neurological, attentional, and motoric processes are facilitated (Maunsell, 2004). Wanting is arbitrated mainly by brain mesocorticolimbic structure which includes projections of midbrain dopamine to objectives of forebrain, involving the nucleus accumbens and additional parts of striatum. The interaction sanctions 'wanting' peaks to be augmented by states of brain that amplify dopamine reactivity, such as tension, emotional exhilaration, related cravings, or inebriation (Anselme, 2016; Berridge, 2012; Robinson & Berridge, 2013). An important motivation of why people with alcohol use disorder find it extremely difficult to stop or control their urge to consume alcohol after a drink or two is due to state-dependent magnification of incentive salience. Their urge to drink more is so enhanced that often, a previously planned one drink turns into multiple drinks or even a lost weekend (Berridge, 2017). Additionally, this is also a reason why under both negative stressors like feeling stressed out, depression etc. and positive stressors like getting a promotion can stimulate susceptibility to relapse in addiction and related disorders (Sinha, 2013). Addiction is not majorly about contentment, liking, necessity or retraction, with respect to this view, as it is about ‘wanting’.

Biological Bases of Dopamine and Reward

Dopamine has a significant role to play in the reward system of brain as in reinforcing the behaviors that results in rewarding outcomes. Dopamine also helps in signaling information that aid thought, learning, movement, decision-making, attention, and emotion. In the reward system, dopamine is made in the cell bodies of ventral tegmental area (VTA) neurons and then transported into the nucleus accumbens, prefrontal cortex (PFC), hippocampus and amygdala.

The increase in dopamine facilitates various effects of addiction drugs including behavioral, cognitive, motivational, and rewarding effects. Drugs of abuse are known to produce positive hedonic reactions and outcomes that are perceived to be rewarding and involve motivational systems responsible for the reinforcement learning of the task or event which includes cues, actions, and the resulting rewards (Keiflin and Janak, 2015; Berridge and Robinson, 2003). Particularly, the sign and amount of the dopamine response is dependent on the expectation value of the reward. So, a surprising and unanticipated rewarding outcome can stimulate a strong increase in the firing of dopamine while an anticipated rewarding outcome produces little to no change.

Reinforcement Learning

Reinforcement learning (RL) is the process of learning the value of choice options to optimize decision making. RL is shaped through iterative updating of anticipated reward values based on reward prediction errors (RPEs), either through positive RPEs (i.e., when an outcome produces a higher reward value than anticipated), or negative RPEs (i.e., when an outcome produces a lower reward value than anticipated). RPE can be both rewarding and punishing as in when the received reward value is more or better than the predicted reward value, it is gratifying and embraced and the action or response leading to this outcome would be repeated in future trials whereas if the received reward value is less or worse than the predicted reward value, it is unwelcomed and the action leading to this outcome would be avoided in future.

In scenarios where an agent is not told which action to take it must learn by trial and error to determine which action yields the most rewarding outcomes or avoids punishments. For RL to be efficient, the agents must be able to sense the state of the environment to some extent should also be able to make decisions affecting that state. The agent should also be able to recognize the goals of the task, situation. Primarily, RL was developed via computational modeling to recognize ideal decisions in a formal task setting which is known as a Markov decision process (MDP). An MDP is a discrete time-based regulatory process and is balanced across these three prime factors: state, action, and reinforcement (Daw, 2003).

The state is important because it can impact which course of action is taken while the action determines the development of the state and hence the attained rewards. Particularly, the state of any time $t+1$, (s_{t+1}) is a probabilistic function of an antecedent state s, and action at time t, a_t which is estimated by the transition distribution $P(s_{t+1}|s_t, a_t)$. A significant assumption of MDP is that the transition property of the state relies solely on the present state and action. The MDP describes the agent's internal account of the process. Reinforcement learning aims at attempting to maximize the reward signal rather than trying to find the hidden answer or right answer. A distinctive feature of reinforcement learning is that it unambiguously considers the entire objective of goal-directed subject interacting with a probabilistic environment. So, unlike other paradigms of machine learning, reinforcement learning relies on the chance of a rewarding outcome that the subject must exploit and make decisions progressively based on how high the probability of an event is happening is based on the previous trials and explore the chance of the new options being rewarding or not by choosing them so that they can relied upon for upcoming trials in the future.

Reward Positivity

The reward positivity (RewP) is a positive EEG deflection that appears at approximately 250 milliseconds following the reward received (Proudfit 2014; Holroyd 2016; Holroyd et al. 2008). The RewP resonates with mechanism of a regulatory function from signals of anterior cingulate cortex (ACC) (Baker, Holroyd, 2011; Holroyd, Umemoto, 2016). Numerous studies have demonstrated that the RewP amplitude reflects RPE which is a primary component of reinforcement learning (Brown, Cavanagh, 2020; Cockburn, Holroyd, 2018). Recent research has demonstrated that the feedback of positive and negative valence results stimulates ERP differences through positively skewing deflection (the RewP) incited by a reward-related neural process as compared to a negatively skewed deflection incited by a punishment-related process. A RPE signal is simulated by RewP such that it is maximum for the unexpected and no rewards and minimum for expected rewards and no rewards. RewP is sensitive to the context and is elicited even when the goal of the task has not been achieved. Furthermore, studies have validated a strong relation between the RewP and the fundamental delta band activity associated (Bernat et al.,2008; 2016). Delta band power is also related to positive RPE (Cavanagh, 2015).

In the existing literature, a great deal of focus has been put on examining the RewP incited by the feedback stimuli in tasks of predicting and learning through reinforcement. The theory of RPE indicates that the RewP is incited by events of rewards that differ from expectation such that they are more rewarding for the positive events as compared to the negative events when both the events have the same likelihood of occurring. Thus, in cases where the trial outcomes that are reliably predicted by predecessor events, the magnitude of RewP to predictive events and subsequent outcomes are inversely related (Holroyd and Coles, 2002). For example, in tasks of learning with the paradigm of trial and error where the responses must be made speedily, the RewP is greater for unpredicted feedback stimuli as compared to for predicted stimuli (Eppinger et al.,2008; Holroyd and Coles, 2002). It has been demonstrated that the RewP is perceptive to subjective and investigational factors for example, if a pleasing picture is followed by the reaction (Brown & Cavanagh, 2018). Also, it is suggested that the RewP is centered around the perspective of global reward value and not the local reward value because the RewP is sensitive to the circumstantial factors that impact task behavior, mood etc. (Kujawa et al; 2012).

Characteristically, the RewP has been evoked with points (Brown, Cavanagh, 2018), upward facing arrows (Angus, Kemkes, Schutter, Harmon-Jones, 2015), money (Bellebaum, Daum, 2008) and while these reward stimulus types are different to each other, they all represent the same broader category: one dimensional reward vs punishment kind of feedback. There is not ample existing literature that investigates other types of rewarding feedback, and this restricts the exploration of margins of RewP (Brown & Cavanagh, 2018).

Electroencephalogram (EEG) research of AUD

There is paucity of robust and reliable ways of probing reward processing to assess sensitivity to addiction. Existing literature have demonstrated that the neural signal of RewP responds significantly across various clinical populations. For example, depressed individuals are characterized by a diminished response to rewarding outcomes and a heightened and sensitive response to punishing/negative outcomes (Cavanagh et al., 2019; Kumar et al., 2008). Also, it has been shown that people with the condition of schizophrenia respond normally to rewards (Gold et al., 2008), even though they have poor operational rates of learning compared to healthy population (Nestor et al., 2014).

No studies to date have examined the RewP in an AUD sample by the means of affective imagery. Moreover, no studies have assessed how history of AUD impacts the RewP, even though, internalizing psychopathologies are positively related to alcohol use disorders (AUDs), and there is evidence that AUDs are characterized by aberrant reward processing styles. It is important to examine RewP in AUD, but since both are correlated with other differences or non-specific influences so it is critical that we assess and analyze to ensure that RewP alterations are specific to alcohol rewards and AUD and not a by-product of mood.

Present Research

The objective of the present research is to examine the sensitivity of the RewP to hedonically affective and alcohol images in individuals with AUD. The RewP has never been assessed in individuals with AUD versus healthy controls by the means of affective imagery. Our first hypothesis is that the EEG feature of RewP is larger in individuals with AUD and that this effect is specific to alcohol-related cues vs. images of puppies. We expect the delta band power to follow the characteristics of RewP. In addition, we hypothesize that a similar, between group pattern (AUD and healthy controls) will be observed in behavioral performances we expect that ratings will be higher to alcohol-related cues for individuals with AUD as compared to benignbeverage cues. We predicted a classic interaction, with RewP amplitudes for the AUD group being for alcohol-related cues while an opposite trend would be observed for the Control group.

Materials and Method

Inclusion/Exclusion Criterion

This study was approved by the Institutional Review Board of the University of New Mexico. The data was collected from the community. We recruited the AUD participants from the ongoing parent grants at University of New Mexico for ABQDRINQ study (NIH GRANT #RO1AA025762). The following inclusion criteria were used for the AUD group- (1) Age 22-55 years; (2) Self-identify as a "[moderate to heavy/binge/weekly] drinker" based on the advertisement; (3) Engage in "hazardous and harmful alcohol use" based on an Alcohol Use Disorder Identification Test (AUDIT) score (Verhoog et.al., 2020); (4) Right-handed. The following exclusion criteria was used for all participants at the baseline appointment at ABQDRINQ study: (1) Currently seeking alcohol treatment or any form of mutual help for drinking (e.g., Alcoholics Anonymous meetings); (2) History of brain injury or neurological diagnoses; (3) Meets criteria for lifetime schizophrenia or bipolar disorder; (4) Current substance abuse or dependence other than nicotine or marijuana (i.e. only substance abuse/dependence that occurred with the year prior to the baseline appointment is exclusionary); (5) Evidence of recent illicit drug (other than marijuana) use on a urine screen; (6) Contraindications for MRI (e.g., medical devices in the body); (10) history of severe alcohol withdrawal (e.g. seizures, tremors, DTs); (11) Potential participants will be excluded if they are suspected of intentionally providing false data, or other reasons that would lead to poor data quality/study performance as determined by sound judgement on the part of the study team. For recruiting the healthy controls, we mandated that the participants do not satisfy any of the exclusion criterion and must score between the range of 0-3 on the AUDIT scale. The control participants were matched for age ranges and sex distribution with the AUD group. Participants were excluded from the control group if (1) they reported to have had a history of head injury resulting in a loss of consciousness for more than five minutes, (2) had a history of seizure or epilepsy, (3) had a history of any psychiatric or neurological disorder, (4) were currently taking any psychiatric or neurological medication or (4) had an AUDIT score>3. All participants were compensated with $ 30/hour for their time and the study lasted for an average of 3 hours.

Questionnaires, Neuropsychological Assessments and Method

The participants completed the informed consent, demographic and SES assessment, handedness, Behavioral Inhibition System/ Behavioral Approach System (BIS/BAS), Beck Depression Inventory (BDI). We used this scale to verify whether any reward positivity effects could be due to depression. Prior research suggests that people suffering with major depression display reduced neural signals in tasks of reward learning, although they learn them equally well (Cavanagh, Bismark, Frank, & Allen, 2019). Data of 2 out of the originally proposed 30 AUD participants was excluded from the analysis due to technical difficulties of EEG set-up. Data of one control participant was removed because of AUDIT score>3 during re-assessment in the lab. Thus, for our final analysis, we had n = 28 (16 female) in the AUD group and n = 27 (16 female) controls. We conducted chi-square tests of independence which showed that there were no statistically significant differences between groups for sex ($p = 0.87$), ethnicity ($p = 0.93$), or race ($p = 0.23$). We conducted independent samples t-tests which revealed no statistically significant differences between groups for age ($p = 0.74$) or years of education ($p = 0.15$). Welch's unequal variances t-tests revealed statistically significant group differences for AUDIT ($p < .001$) and BDI scores ($p = 0.02$). Within the AUD group, AUDIT scores correlated with BDI (rho = 0.403, $p = 0.03$) and years of education (rho = 0.454, $p = 0.01$), see Figures 1 and 2. The tasks for this experiment were programmed in Matlab using Psychtoolbox (Brainard, 1997). All the participants completed the Image Rating and RL State tasks.

Table 1. Participant Demographics. Means and SD.

		AUD	**Control**
N (female)		28 (16)	27 (16)
Age		38.6 (9.43)	37.7 (10.7)
Years of education		15 (2.3)	16.1 (2.96)
AUDIT		10.5 (5.57)*	1.33 (0.92)*
BDI		11(12.1)*	4.63(7.69)*
BIS Total		14.6 (2.62)	14.7 (2.55)
BAS Total		22.6 (5.04)	24 (6.04)
BAS Drive		8.43 (2.46)	7.67 (2.24)
BAS Fun Seeking		6.89 (1.85)	8.11 (2.62)
BAS Reward Responsiveness		7.25 (1.90)	8.19 (2.24)
Ethnicity	Hispanic:	9	10
	Non-Hispanic:	17	18

Figure 1. shows the scatter plot of BDI Vs AUDIT score within the AUD group. There was a significant positive correlation between Audit score and BDI score in the AUD group (p<.05).

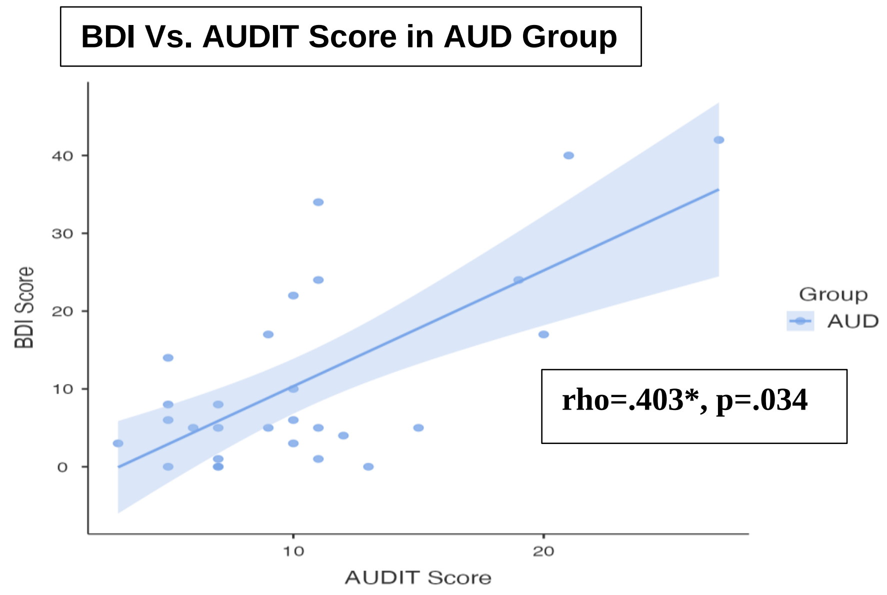


Figure 1. Scatter Plot of BDI Vs AUDIT score within the AUD group.

Figure 2. shows the scatter plot of AUDIT score vs. education within the AUD group There was a significant correlation between AUDIT score and years of education in the AUD group (p<.05).

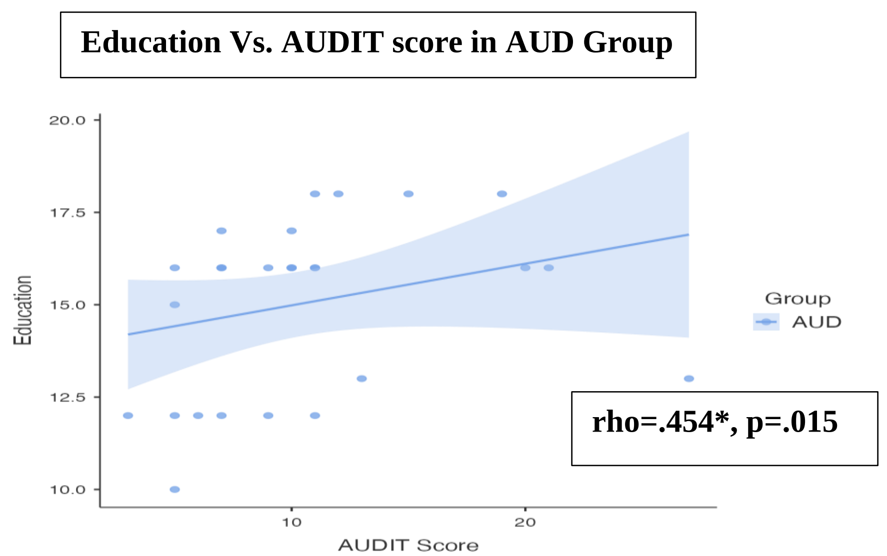


Figure 2. Scatter Plot of AUDIT score vs. education within the AUD group.

Tasks

Image Rating Task

We administered an image rating task before the reinforcement learning task to obtain ratings of pleasantness for the affective imagery used. We presented the participants with an image from one of the five categories of affective image: puppies, sceneries of nature, babies, chairs, and negative images (e.g., a corpse). The classes of these affective images were based on the picture categories that were rated as very positive, neutral, or very negative from the International Affective Picture System (IAPS; (Lang et al., 2008) but these specific pictures were selected from cyberspace searches (e.g. “high-definition puppy images”). Participants rated how pleasant they felt the presented image was on a scale from 1 (very unpleasant) to 9 (very pleasant). Irrespective of what they rated as most pleasant, the image of puppy or alcohol was used as the image rewards in the subsequent learning task. Previously, extensive pilot testing has shown that the image category of puppies was reliably most pleasantly rated affective imagery (Brown et. al., 2021). See Figure 3b for the behavioral data of image rating task.

RL State Task

For the RL State task, we adapted a very close variant of Affective State Reward Task (Brown et. al., 2021): In their experiment, they used images of puppies and cows. The pilot data of this study suggested that puppies were reliably rated to be more pleasant than cows. So, for our study, we replaced the images of cows with images of alcohol while retaining the images of puppies as it was in the original task. See Figure 3a. for an example of a typical RL State task. We selected all the images from the Internet using the keywords (“high-definition alcohol images”). Participants were presented with an equal number of high-definition images split across the two categories- alcohol-related images and likable images of puppies. We examined all the images in order to make sure that no image appears blurry or distorted. Images were not repeated and were only presented once. Dimensions of all images were equal. The participants were required to press left or right key to choose either of the cues. The aim was for them to learn to assign either a left or a right button push to an image and choose the one that is more rewarding. The reward was presentation of green screen while the punishment was presentation of red screen. After each trial, the screen turned red or green to indicate punishment or reward as shown in Figure 2. However, this colored screen feedback was followed by an affective image of puppy or alcohol but these picture type had nothing to do with whether they pressed the correct button or not and did not affect their feedback type. The participants were told about this. The average time taken to complete this task was 19.3 minutes. There was an image on the screen and then (after a short time) trial feedback (for example, a green screen) was presented. Colored

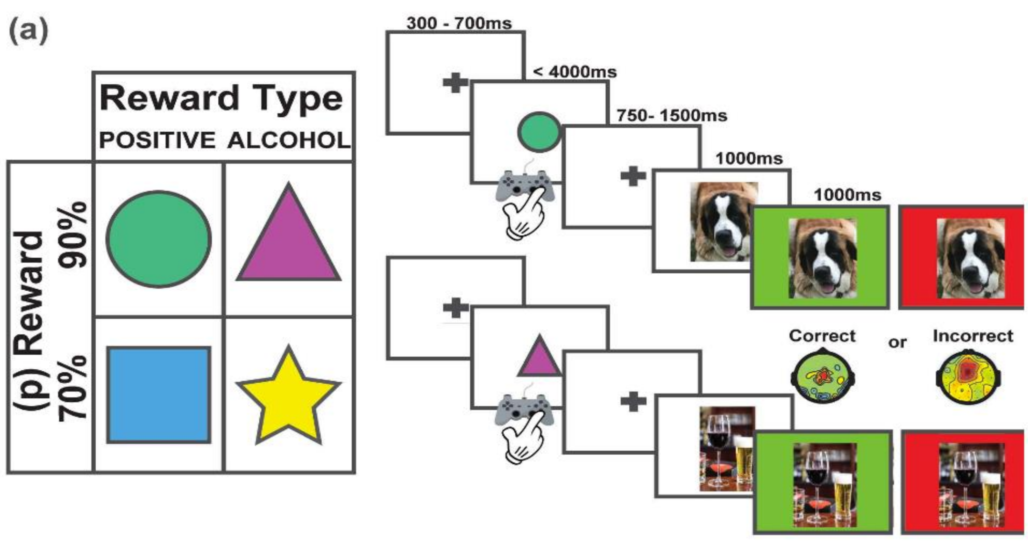
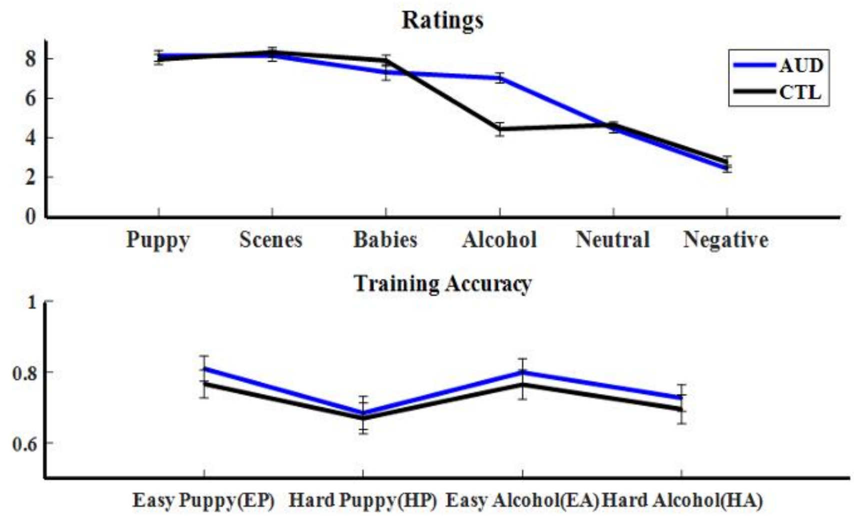


Figure 3a. Affective Imaging and Reinforcement Learning Task and behavioral results. As shown in the a). In the display of a typical experimental trial. During the task, participants were presented with a cue (a) predicting different reinforcing rates (easy: 90% vs. hard: 70% reinforcement) and an affective imagery (puppy vs. alcohol) followed by the feedback (reward: green screen vs. punishment: red screen).

feedback was presented to the participant for 1000ms.



3 b). Behavioral results of Rating task and the accuracy across the two groups.

EEG Recording and Preprocessing

Electrophysiological data was recorded using a Brain Vision System (Brain Products GmbH, Munich, Germany) with low and high cut off range of .01-100Hz. An EEG cap embedded with 64 Ag-AgCl electrodes with a sampling rate of 500Hz was placed and fixed on the participant's head. The FPz was the ground electrode and CPz was the reference electrode. We recorded the vertical electrooculogram (VEOG) generated by eyeblinks by fixing two auxiliary electrodes to the superior and inferior region of the left eye.

We processed all the EEG data in EEGlab (Delorme and Maekig, 2004). We first averaged the referencing (using EEGlab function pop.reref.m) followed by removing data of mastoid recordings (TP9 and TP10) along with the very ventral electrodes (FT9 and FT10). Thus, the EEG data was reexamined for the rest of the 60 electrodes. FASTER (Nolan et al., 2010) was used to detectartifacts in each epoch in order to reject later. We removed eye blink activities following ICA (runica; Makeig, Bell, Jung, & Sejnowski, 1996). RewP was quantified as the average amplitude from 200-400ms at the reference electrode site CPz.

Results

Ratings

As shown in figure 1b, both the groups rated all stimuli similarly, with the exception for alcohol-cues in the AUD group. Only the puppy and alcohol images here were used for the subsequent study though, and there was no between group differences in puppy image ratings ($F(1,53) = .07, p=.78$), however there was a significant group difference in alcohol images ($F(1,50.8)=32.22, p<.001$).

EEG Results

Our hypothesis was that reward positivity is larger to alcohol-related cues as compared to puppy-related cues in individuals with AUD. See Figure 5 for the two groups for initial feedback for affective imagery type. We conducted a 2*2 ANOVA between the groups (AUD and control), the RewP amplitude (alcohol-related and puppy cues) and all ps>.50 (see Supplementary Table 2). This analysis failed to reveal any significant main effects or interactions between the groups across the cue types. Brown et al, (2021) showed that there was a significant main effect of difficulty (hard>easy) on RewP amplitudes. We conducted a 2*2*2 ANOVA between the groups (AUD and control), the types of imagery (alcohol-related and control puppies' cues) and difficulty (easy and hard), all ps>.50 (see Supplementary Table 3). This analysis failed to reveal any significant main effects or interactions between the groups. This finding failed to support our hypothesis since there was not a statistically significant difference in RewP evoked for alcohol-related vs puppy related images across the groups of AUD and controls. Also, upon testing we found that there was not a significant effect of difficulty on puppy vs alcohol related RewP amplitude (see Figure 6). We then tested correlations.

Figure 4. shows the Topographical Plots of Reward and Punishments

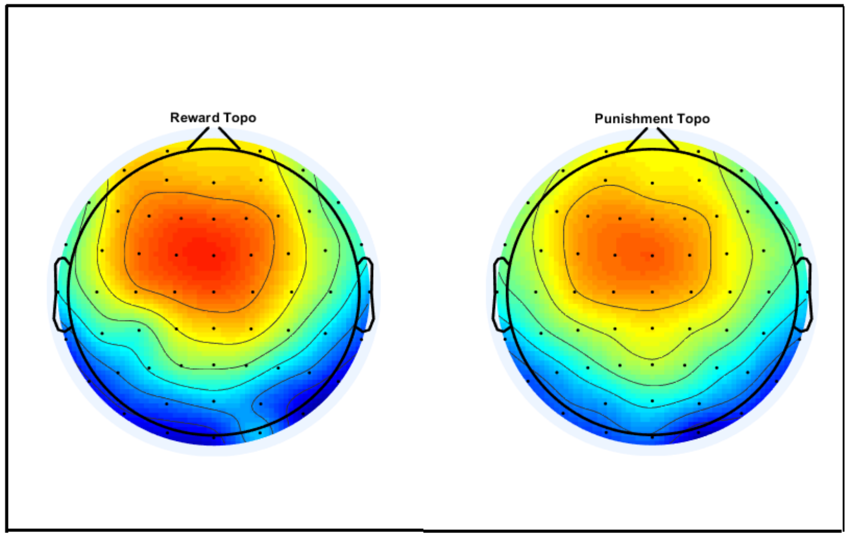


Figure 4. Topographical Plots

Figure 5. shows the ERP Plots of the two groups for initial Feedback of Affective Imagery Type. Even though the hedonic outcome was subsequent pictures (a) RewP (200 – 400ms) did not differ between Image Type conditions. There was not a significant ERP amplitude differences between the conditions.

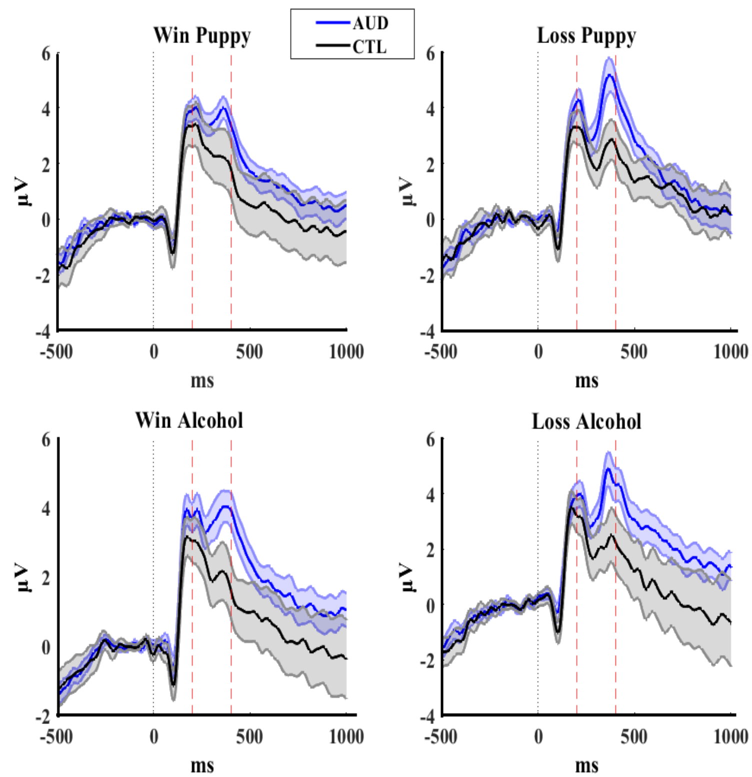


Figure 5. ERP Plots of the two groups for initial Feedback of Affective Imagery Type.

Figure 6 shows the ERP plots of rating difference by RewP amplitude difference across difficulty levels. This analysis failed to reveal any significant effect of difficulty on puppy-alcohol RewP amplitudes, suggesting that feedback-related ERPs are not sensitive to more surprising outcomes, and there was no difference in image type observed, suggesting that across group dynamics of the RewP is not affected by emotional affective imagery.

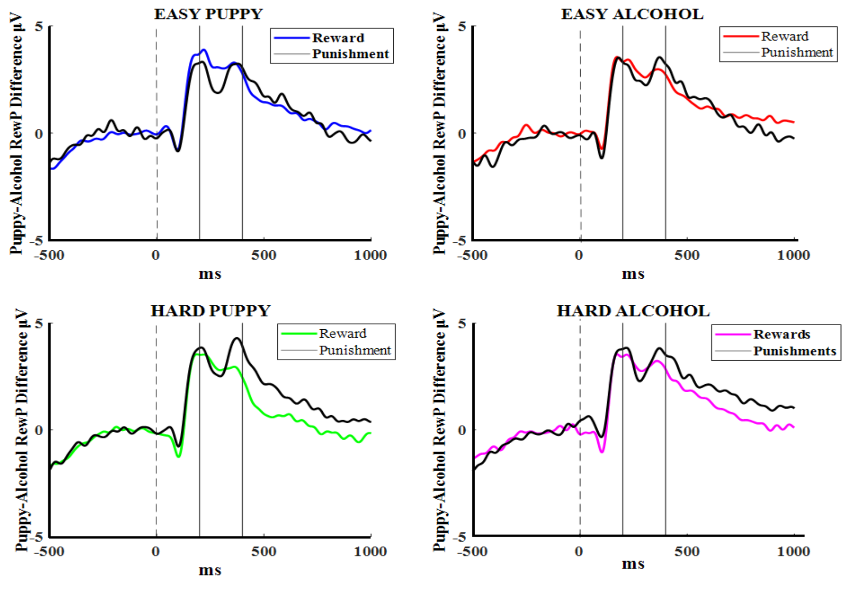


Figure 6. ERP Plots of Rating difference by RewP amplitude difference across Difficulty Levels.

Figure 7. shows the scatterplot of RewP amplitude difference and Rating difference. The correlation between pup-alcohol rating difference and pup-alcohol RewP amplitude for all participants was not significant (rho=.252, p=.05).

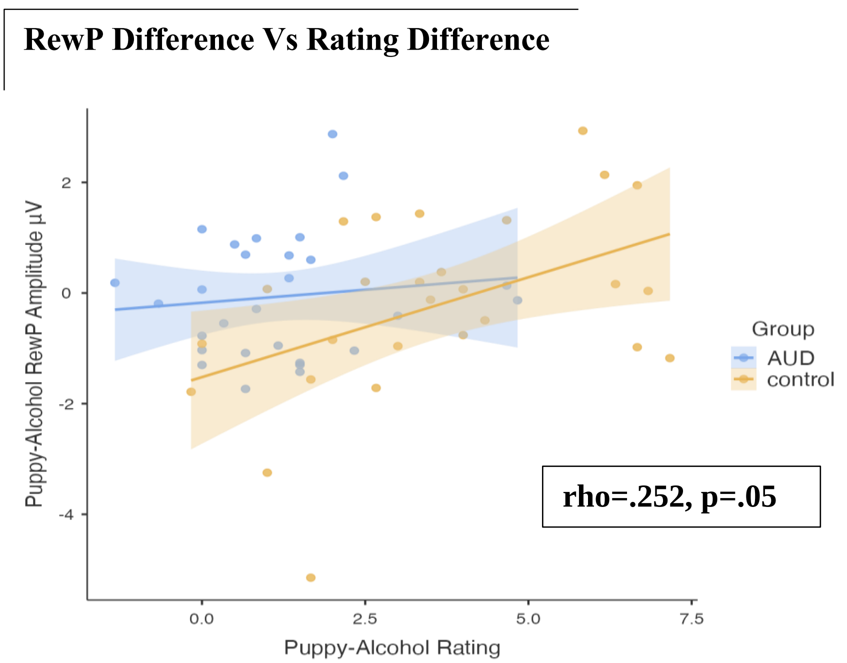


Figure 7. Scatterplot of RewP amplitude difference and Rating difference.

Figure 8. shows the scatter plots of Pleasantness Ratings of Affective Imagery Types Vs. RewP across Difficulty Conditions

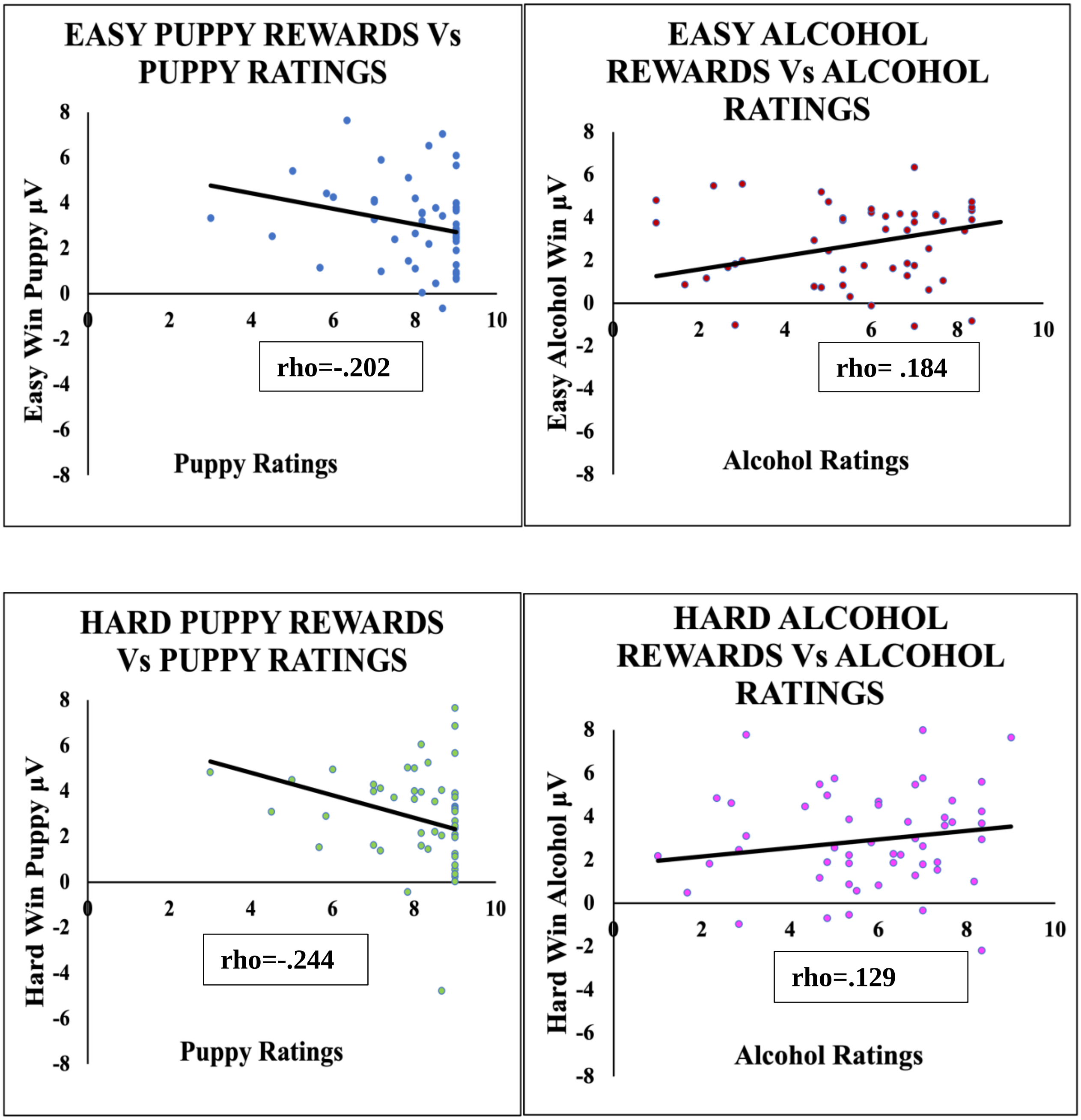


Figure 8. Scatter Plots of Puppy Ratings and Alcohol Ratings vs RewP amplitude difference across Easy & Hard Rewards Conditions of Puppy and Alcohol. No significant correlations were found.

Figure 9. shows the scatter Plots of Rating difference Vs. RewP across Difficulty Conditions

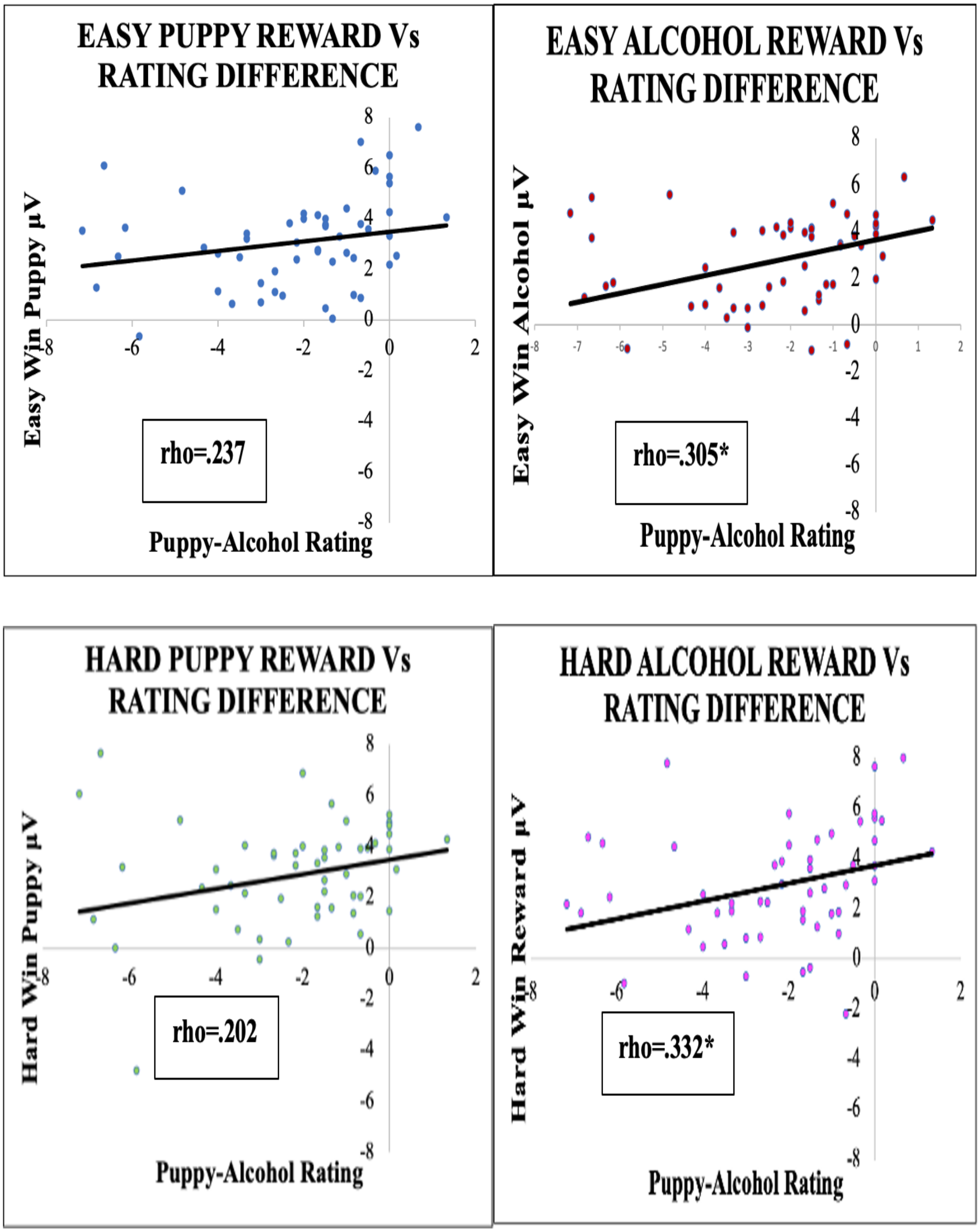


Figure 9. Scatter Plots of Rating difference and RewP amplitude difference across Easy & Hard Rewards Conditions of Puppy vs Alcohol. The correlations between easy alcohol rewards vs rating difference and hard alcohol rewards vs rating difference were significant, $p<.05$.

Figure 10. shows the scatter plot of Rating difference Vs. RewP across Easy & Hard Rewards Combined Conditions.

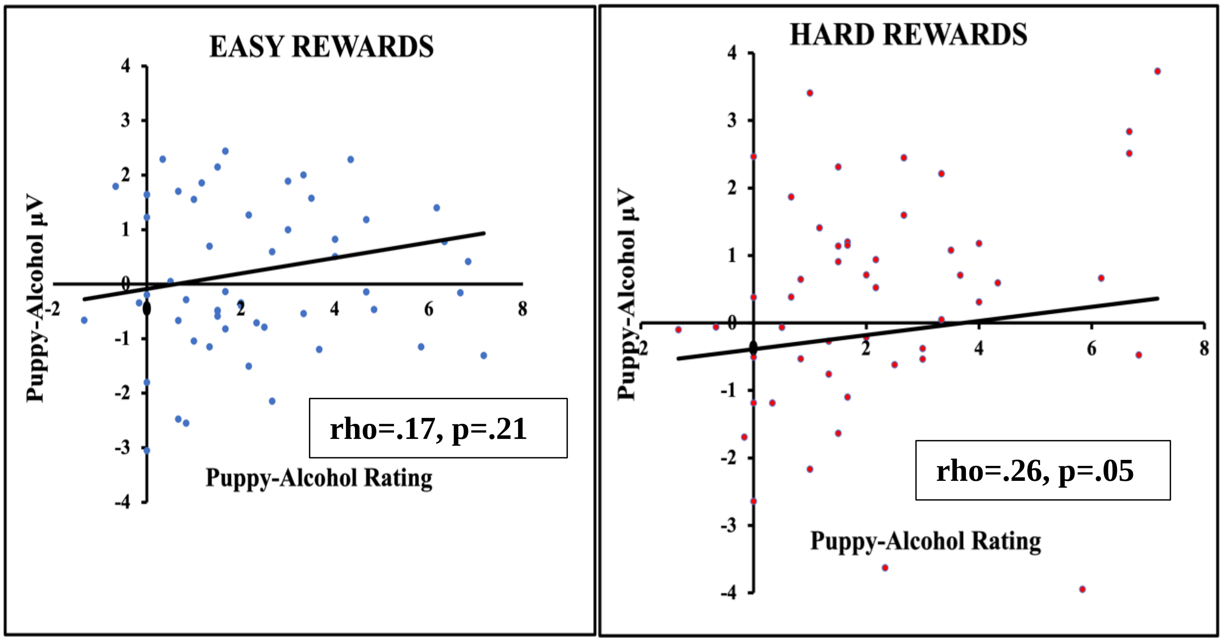


Figure 10. Scatter Plot of Rating difference and RewP amplitude difference across Easy & Hard Rewards Combined Conditions. The correlations were not significant.

Figures 8, 9, and 10 shows the scatterplots for RewP amplitude differences and pleasantness rating differences. The bottom panel displays change-score correlations between pleasantness rating and ERPs contrasting puppy and alcohol images. For both the hard condition (70% reinforcement rate), and the easy condition (90% reinforcement rates), the correlation was not significant (p>=.05).

Correlations: Just AUD Group

Figure 11. Scatter plot between AUDIT score and RewP amplitude difference. There was a significant positive correlation between audit score and alcohol-pup RewP amplitude in the AUD group(p<.05)

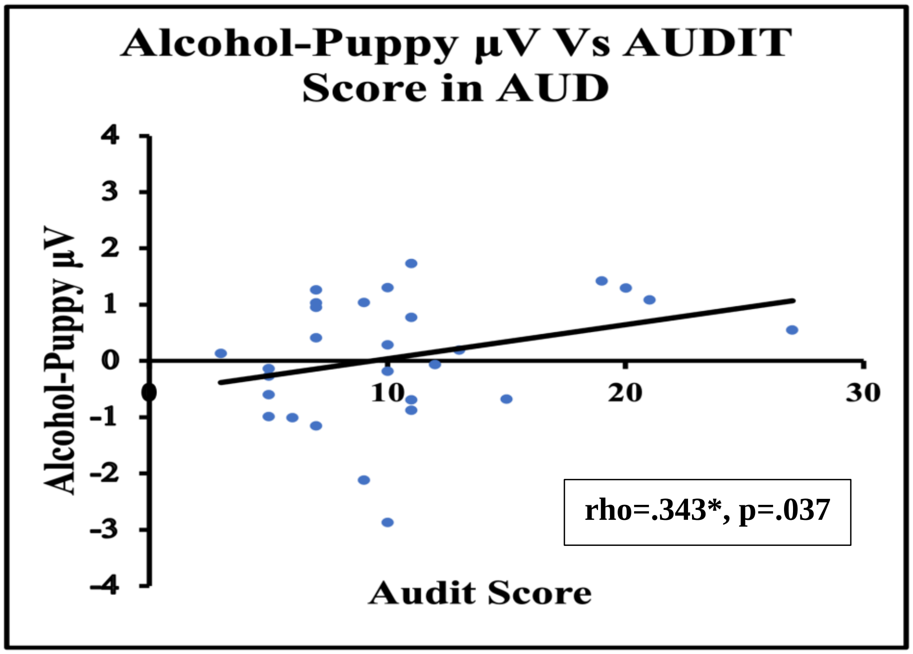


Figure 11. Scatter plot between AUDIT score and RewP.

Figure 12. shows the correlation between RewP amplitude difference and years of education in the AUD group. There was no correlation between years of education and alcohol-pup µV amplitude in the AUD group(p>.05).

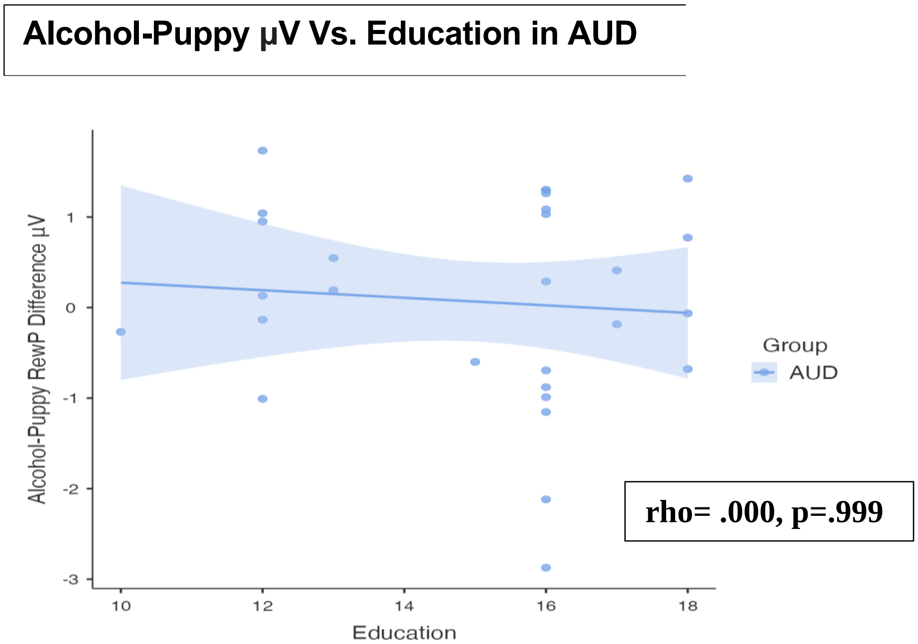


Figure 12. Scatter plot between education and RewP.

Figure 13. shows the scatterplot between BDI score and RewP amplitude difference. There was not a significant correlation between the BDI score and alcohol-pup μV amplitude in the AUD group (p>.05).

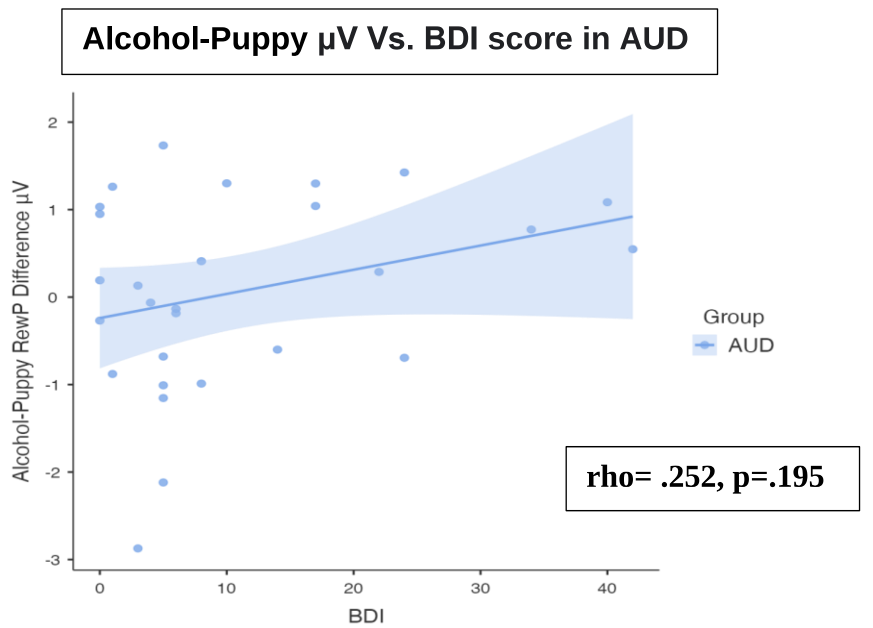


Figure 13. Scatter plot between BDI score and RewP.

AUDIT score correlated significantly with pleasantness ratings for alcohol images (rho=.737, p<.001, see Figure 3b). Also, as mentioned earlier, AUDIT score in control group is meaningless, so here we only looked within the AUD Group (see Figures 11, 12 and 13). As shown in Figure 11, the correlation between RewP amplitude difference and AUDIT score in the AUD group was significant (spearman's rho=.343, p<.05). To test whether the BDI score, or education could be affecting this result, we tested their correlations with RewP amplitude difference, and they were not significant (Figure 12 and 13). In sum, AUDIT score predicted RewP enhancements due to imagery relevant to AUD (i.e., alcohol images).

Discussion

In this study we revealed that within the AUD group, there was a significant correlation between AUDIT score and RewP amplitude, suggesting that people who consume alcoholic drinks more are more responsive to having alcohol imagery boost their intrinsic reward signal. What makes this study novel is that aberrant salience to alcohol imagery has never been used to boost this intrinsic reward signal in AUD population.

We first demonstrated that the AUD group rated the pictures of alcohol to be more pleasant than controls. There was no difference in the RewP to affective imagery type as function of group, suggesting that the across group dynamics of the RewP is not affected by emotional affective imagery. Taken together, these findings support our hypothesis that the more a person is likely to consume alcohol in terms of quantity and frequency, the more their RewP is likely to be boosted due to alcohol-related outcomes.

Recent conceptualizations of reward disorders propose a critical significance for visuospatial/sensory cognition in desiring and drug use (Kavanagh, May, & Andrade, 2012). According to elaborated intrusion theory, sensory cues and functional bodily states are anticipated to aid cognitive progressions that regulate and strengthen craving by the means of drug associated sensitive imagery, which boosts through controlled cognitive processes (elaborated intrusion theory; May, Andrade, Panabokke, & Kavanagh, 2004). The findings of existing literature on AUD and reward reactivity suggests that AUD is correlated with an increased reward reactivity and subsequently diverges from the reward deficiency syndrome. Other studies have demonstrated that individuals at-risk of developing alcoholism and with current AUDs chronicle an increase in reward pleasure and responsiveness (Nicola et al., 2015) and show more responses to affective rewards, as compared to individuals without AUD (Boecker et al.,2017; Hasler et al., 2013).

In our sample the AUDIT score was significantly correlated with the BDI score which is consistent with the results of previous studies that describe how depressive symptoms are common among individuals with alcohol and other drugs disorders (Compton et al., 2007 & Hasin et al; 2007). People with alcohol and other drug disorder are reportedly two to four times more likely to have major depression as compared to individuals in the general population (Compton et al., 2007 & Hasin et al; 2007). Depressive symptoms impact 30–45% of people pursuing treatment for substance misuse (Grant et al., 2004). Notably, in the current analysis, BDI scores did not account for variance in RewP change specific to alcohol cues.

This study replicates a part of the findings shown by (Brown et al, 2021) that there was no main effect of RewP evoked via affective imagery across groups, only interindividual differences. Taken together, it seems that the effect of affective imagery on the RewP is highly characteristic and possibly objective of other moderators like scale (Brown & Cavanagh, 2018) or reward surprise in clinical samples. By adapting norms of reinforcement learning and coupling the accomplishment of reward with an affective imagery following its receipt, we evaluated RewP in the context of affectively salient rewards. With these novel findings, the prospect of testing new hypotheses linking multifaceted rewards stimulating intrinsic states of motivation can be of vital interest. This research is distinctive because the RewP has never been assessed in individuals with AUD versus healthy controls by the means of emotional affective imagery of which we are aware. Additionally, in the current study the sample size was relatively modest and consisted of mostly middle-aged adults.

Limitations and Future Directions

The first hypothesis of our study was that reward positivity would be larger to alcohol-related cues as compared to puppy-related cues in individuals with AUD. This was not supported because there were no group differences in the reward positivity elicited by the type of affective imagery. Our results do not indicate that any affectively pleasant images evoked condition specific and/or group specific RewP enhancement. However, our data clearly suggest that a higher AUDIT score predicts larger RewPs to affectively pleasant stimuli in the AUD group.

In the current study some of our participants from the AUD group reported very low AUDIT scores at the time of this study compared to when they were initially recruited for the ABQDRINQ study (our subject pool for recruiting the AUDs) where they qualified as AUDs. Thus, upcoming research studies with larger sample sizes and well-defined phenotypes to distinguish the groups are required in order to examine moderators of interest and duplicate the observed group differences. Lastly, the current study did not involve a group of participants with AUD history, neither did it investigate the family history of AUD in participants. It will be significant for prospective studies to examine if adults with AUD with an existing family history of AUD would also demonstrate a boosted RewP, or if this reaction is only detected among individuals with AUD and current externalizing psychopathology. Future studies may need to intensify additional recruitment criterion in order to make a more distinguished demarcations between the two groups. Changing the affective imagery type from a generally likable picture (puppy as used in the current study) to a generally neutral picture (for example: chair or switches) may lead to an elicitation of RewP sensitive to affective imagery.

Conclusions

In conclusion, our major findings were that the AUD group rated the pictures of alcohol to be more pleasant than controls. There was no difference in the RewP to affective imagery type as function of group, suggesting that the across group dynamics of the RewP is not affected by emotional affective imagery. Next, we showed that within the AUD group, there was a significant correlation between AUDIT score and the RewP amplitude difference. This suggests that the within-group dynamics of RewP is affected by emotional affective imagery. Our analysis showed that RewP is sensitive to liking of images of alcoholic beverages in individuals with alcohol use disorder. This study replicates a part of the findings shown by (Brown et. al., 2021) that there is no main effect of RewP evoked via hedonistic affective imagery across groups, only interindividual differences within group. Our findings suggest that alcohol-specific imagery boosts the reward positivity in individuals with AUD, thus demonstrating a mechanism for linking biased attention with reward integration for addiction-specific stimuli.

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Supplementary Tables

*Table 2: 2*2 ANOVA of RewP Amplitude for Image Types across Groups*

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η²
RewP Amplitude	0.589	1	0.589	0.578	0.451	0.004
RewP Amplitude ✻ Group	0.182	1	0.182	0.179	0.674	0.001
Residual	54.012	53	1.019			

Note. Type 3 Sums of Squares

Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η²
Group	4.91	1	4.91	3.65	0.062	0.037
Residual	71.29	53	1.35			

Note. Type 3 Sums of Squares

*Table 3: 2*2*2 ANOVA Table of Difficulty Level, Image Type across Groups*

Within Subjects Effects

	Sum of Squares	**df**	**Mean Square**	**F**	**p**	**η²**
Difficulty Level	0.1646	1	0.1646	0.0834	0.774	0.000
Difficulty Level ✻ Group	0.3568	1	0.3568	0.1806	0.673	0.000
Residual	104.6769	53	1.9750			
Image Type	0.5692	1	0.5692	0.2129	0.646	0.000
Image Type ✻ Group	1.9211	1	1.9211	0.7187	0.400	0.001
Residual	141.6794	53	2.6732			
Difficulty Level ✻ Image Type	1.8806	1	1.8806	0.9904	0.324	0.001
Difficulty Level ✻ Image Type ✻ Group	0.0292	1	0.0292	0.0154	0.902	0.000
Residual	100.6363	53	1.8988			

Note. Type 3 Sums of Squares

Between Subjects Effects

	Sum of Squares	**df**	**Mean Square**	**F**	**p**	**η²**
Group	148	1	147.8	3.36	0.073	0.052
Residual	2334	53	44.0			

Note. Type 3 Sums of Squares

Table 4. Independent Samples T-Test By Group

Independent Samples T-Test

		Statistic	df	p
Punishment	Welch's t	-2.17	41.3	0.036
Reward	Welch's t	-1.87	35.5	0.069