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Parental Alcohol Use Predicts Neural Emotion Reactivity and Substance Use Intentions in Early Adolescence

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Abstract

Parents' alcohol use may influence adolescent substance use and substance use intentions. Prior research has linked adolescents' emotion reactivity with parental drinking behaviors and adolescent substance use. The present study investigated whether sub-clinical maternal alcohol use relates to adolescent neural emotion reactivity and substance use intentions in early adolescence. Early adolescents (N = 70) viewed emotional images during a fMRI scan and completed a questionnaire about substance use intentions. Their mothers reported past 30-day alcohol use. Results showed that greater frequency of maternal alcohol use predicted adolescents' substance use intentions. In addition, maternal alcohol use predicted adolescent blunted responses to positive emotional images in the ventromedial prefrontal cortex (vmPFC) and bilateral anterior cingulate cortex (ACC). There was no relationship between neural emotion reactivity and adolescent substance use intentions. Findings suggest that parental alcohol use may relate to adolescent's development of reward and positive emotion processing systems, even at sub-clinical levels of drinking.

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Introduction

Substance use during adolescence is a prominent public health concern in the U.S., with an approximated 54% of adolescents reporting having tried alcohol and 43% having tried illicit drugs before leaving high school (Johnston et al., 2022). For younger teens, self-reported intentions to use substances provides a useful proxy for predicting later consumption (Andrews et al., 2003; Hamilton et al., 2022; Webb et al., 1996). For example, longitudinal studies of children and adolescents have shown that intentions to use substances in early adolescence significantly predicted future use (Andrews et al., 2003; Webb et al., 1996). One important predictor of adolescent substance use and substance use intentions may be parental alcohol use. Parents' alcohol use has been linked to early adolescent substance use intentions (Tildesley & Andrews, 2008) and adolescent substance use (Chassin et al., 1996; Reich et al., 1993). This connection appears even at sub-clinical levels of parental drinking (Cox et al., 2018; Rossow et al., 2016; Ryan et al., 2010; Tildesley & Andrews, 2008; van der Zwaluw et al., 2008).

While the connection between parental alcohol use and risk for adolescent substance use has been established, there is a need to better understand the mechanisms by which parents' alcohol use creates risk for youth. One possible mechanism may be youth's emotional functioning. Specifically, parental alcohol use may lead to alterations in youth's negative and positive emotional arousal, which then may be related to their substance use risk. Further evaluation of associations among parental alcohol use, emotional functioning in adolescents, and adolescents' risk for substance use may be useful to understand the relationship between parental drinking and adolescent substance use and inform targets for prevention of substance use behaviors in youth.

As such, the present study examined links between maternal drinking, negative and positive emotion reactivity, and substance use intentions in early adolescents. We particularly focus on adolescents' neural emotion processing as emotion-related neural systems are rapidly developing in early adolescence (Casey et al., 2019; Somerville et al., 2010), have been related to parental factors (Tan et al., 2020), and may be biological risk factors for adolescent SU (Chaplin et al., 2019; Nikolova et al., 2016). Further, neuroimaging has the benefit of detecting subtle markers of risk for adolescent substance use that are not easily captured with behavioral methods (Hamidullah et al., 2020; Ochsner et al., 2012). Thus, findings from neuroimaging studies can add to knowledge gained from behavioral studies and identify more nuanced targets

for prevention efforts. To our knowledge, no studies to date have investigated associations between parental alcohol use that is sub-clinical (not an alcohol use disorder) and adolescent neural emotion reactivity. Further knowledge of how sub-clinical parental alcohol use relates to early adolescent neural emotion reactivity may help us understand whether patterns observed in adolescents of parents with alcohol use disorder (AUD) are also observed in adolescents whose parents drink sub-clinically.

Parental Alcohol Use and Adolescent Substance Use and Intentions

Parents' drinking behaviors have been shown to influence adolescent substance use both for parents with alcohol use disorders (AUDs) and for parents who drink sub-clinically (Chassin et al., 1996; Rossow et al., 2016; Ryan et al., 2010). In a review of 77 longitudinal studies of parent factors associated with adolescent alcohol use, parent drinking (including sub-clinical drinking in community samples) was associated with earlier initiation of alcohol use and higher consumption of alcohol in adolescents (Ryan et al., 2010). Parental alcohol use has also been shown to relate to greater adolescent use of substances more generally (Chassin et al., 1996). While adolescent substance use intentions have been studied less frequently, a longitudinal investigation of the influence of parental alcohol use on children's alcohol use intentions demonstrated significant effects of parental sub-clinical drinking on children's intentions to use alcohol in adolescence (Tildesley & Andrews, 2008). In addition, parental sub-clinical alcohol use has been associated with greater adolescent alcohol use intentions in conjunction with parents' pro-alcohol communication (Kam et al., 2017). In sum, several studies have found connections between AUD and sub-clinical parental drinking and adolescent substance use and substance use intentions. However, further research is needed to understand potential mechanisms for this association.

Parental Alcohol Use and Adolescent Emotion Functioning

There are several potential mechanisms that may explain the influence of parental alcohol use on adolescent substance use and substance use intentions, including genetic mechanisms, parental modeling of drinking behavior, and inconsistent/negative parenting, (Chassin et al., 1993; Cox et al., 2018; Latendresse et al., 2008; Ryan et al., 2010; Vrieze et al., 2013). One important mechanism may be adolescents' emotional functioning, including their neural emotional reactivity. Parents' alcohol use may be related to their children's emotion functioning in several ways. Parents who drink more alcohol may have altered neural emotion reactivity themselves that is passed down to their children behaviorally through modeling of high emotional reactivity or biologically through genetic predisposition to heightened emotional responses

(Glaser et al., 2014; Zink, 2016). Parental drinking could also lead to compromised parenting behaviors (e.g., more negative parenting, less parental warmth, less monitoring) (Chassin et al., 1993; Eiden et al., 2007, 2009), which then may lead to adolescents' altered neural emotion reactivity through behavioral and also biological mechanisms (e.g., impacts on the developing brain) (Chaplin et al., 2019; Morris et al., 2007).

Behavioral Studies. Prior studies have examined associations between parental drinking and emotion reactivity and regulation in adolescents. Studies using behavioral methods have found that parental AUD is associated with and predictive of heightened negative affect and difficulties with emotion regulation in children and adolescents (Chassin et al., 1993; Eiden et al., 2004, 2007; Eisenberg et al., 2010; Iacopetti et al., 2021; Shadur & Hussong, 2019; Wasserman et al., 2020). Sub-clinical parental drinking has been less studied, but has been associated with child externalizing and internalizing symptoms that are related to higher emotional reactivity (Chatterji & Markowitz, 2001; Homish et al., 2010).

fMRI Studies. Previous research has also examined parental drinking in association with children's neural emotional reactivity. Studies have demonstrated differences in neural functioning in response to emotional pictures and words in youth with a family history of AUD in brain regions including the amygdala, precentral gyrus, medial prefrontal cortex (mPFC), bilateral orbital frontal gyrus, left insula, putamen, ventral striatum, nucleus accumbens, precuneus, occipital cortex, and superior temporal gyrus (STG) (Cservenka et al., 2014; Hardee et al., 2017; Heitzeg et al., 2008; Hulvershorn et al., 2013). For example, Hulvershorn et al. (2013) found that greater activation to negative emotional faces in the medial prefrontal cortex, precuneus, and occipital cortex for early adolescent children of a parent with AUD which were associated with emotion regulation difficulties.

With regards to positive emotion processing, a few studies have found differences in neural response to positive or rewarding stimuli in children with a parent with AUD. In one study, Cservenka et al. (2014) found that family history of AUD predicted blunted neural activation to positive emotional images in the STG, an area associated with difficulty discriminating emotion. Some studies have also looked at differences in neural response to reward stimuli (e.g., winning money) and have found that adolescents and young adults with a parent with AUD show blunted activation in the insula and nucleus accumbens in response to rewards (Kirk-Provencher et al., 2024; Martz et al., 2022). These studies on parental AUD suggest that parental drinking may be associated with altered adolescent emotion-related neural reactivity. However, to our knowledge, no studies to date have investigated impacts of sub-clinical levels of parental alcohol use on adolescent

emotion-related brain function. Given that approximately 86% of adults in the United States report drinking alcohol, many of whom do not have an AUD, it is important to understand any potential effects of sub-clinical parental drinking on children's emotion functioning and substance use (National Institute on Alcohol Abuse and Alcoholism (NIAAA), 2023a).

Emotion Functioning and Adolescent Substance Use

Theorists have proposed that altered emotional arousal and emotion regulation can create risk for adolescent substance use (Chaplin et al., 2018; Rakesh et al., 2020). For example, adolescents may seek out substances to manage high negative emotional arousal (i.e., self-medication and stress arousal hypotheses) (Chaplin et al., 2018; Khantzian, 1997; Sinha, 2008) or to reach more positive emotional states as part of sensation-seeking, reward system dysfunction, or as part of positive urgency (Gonçalves et al., 2022; Hammerslag & Gulley, 2016). Altered neural reactivity to negative emotional stimuli has been associated with adolescent substance use and substance use problems in regions including the amygdala, putamen, nucleus accumbens, cingulate cortex, insula, and prefrontal regions, with some studies finding higher activation to negative emotional stimuli associated with substance use and some lower activation (Chaplin et al., 2019; Heitzeg et al., 2008; Jones et al., 2023; Leiker et al., 2019; Spechler et al., 2015). Similarly, altered responses to rewarding and positive emotional stimuli has been associated with adolescent substance use in the amygdala, precuneus, striatum, insula, cingulate cortex, and prefrontal regions, again with some studies finding higher and some lower activation to positive and rewarding stimuli associated with substance use and substance use problems (Aloi et al., 2018; Demidenko et al., 2020; Leiker et al., 2019; McQuaid et al., 2022). Overall, several studies have found associations between neural negative and positive emotion reactivity and adolescent substance use. However, many of the above studies are with older adolescents and no study to our knowledge has looked at the relationship between neural emotion reactivity and substance use intentions during early adolescence.

The Present Study

The present study will add to the literature on parental alcohol use, adolescent emotion functioning, and adolescent substance use by examining associations among mothers' sub-clinical alcohol use, adolescent emotion-related neural responses, and substance use intentions in early adolescents. In doing so, we will address several important gaps in the literature. First, it will add to a relatively small literature that has evaluated parents' sub-clinical drinking predicting substance use intentions in early adolescence. Second, the present

study is the first to evaluate the impacts of sub-clinical maternal alcohol use on adolescent emotion reactivity given that, as prior reviews have noted (Rossow et al., 2016), the literature on sub-clinical parental alcohol use has focused primarily on substance-related outcomes. Third, the present study adds to the literature on associations between adolescent neural emotion reactivity and substance use by examining neural emotion reactivity and substance use intentions in early adolescents.

Maternal Alcohol Use. The present study assessed sub-clinical alcohol use in mothers of early adolescents and will focus on the influence of maternal drinking behaviors on adolescent neural emotion reactivity and substance use intentions. Mothers spend more time with their children on average than fathers and thus may be an important socialization context for alcohol (Schaeffer & Aragão, 2023; Wang, 2013). In addition, rates of alcohol use in women are increasing and they face greater risks of health issues related to alcohol, yet women's alcohol use is understudied (Grucza et al., 2018; National Institute on Alcohol Abuse and Alcoholism (NIAAA), 2023b). Thus, it is important to understand the implications that maternal alcohol use may have on adolescents, even at sub-clinical levels.

Regions of Interest. We chose three regions of interest in which to investigate neural emotion reactivity: the amygdala, anterior cingulate cortex (ACC), and the ventromedial prefrontal cortex (vmPFC). These regions were selected due to their demonstrated involvement in different aspects of emotion processing, including initiation of primary emotion signals, integration of emotional and sensory information, and higher cognitive processing of emotion (Giuliani et al., 2011; Stevens et al., 2011; Šimić et al., 2021). Additionally, activation in all three regions to emotional stimuli has been associated with substance use (Cservenka et al., 2014; Hardee et al., 2017; Heitzeg et al., 2008; Hiser & Koenigs, 2018; Seo et al., 2013).

Hypotheses

First, we hypothesize that, consistent with previous findings, higher maternal alcohol use will predict greater intentions for substance use in early adolescence. Second, we hypothesize that maternal alcohol consumption will predict adolescent emotion-related neural response to negative (- neutral) emotional images and to positive (- neutral) emotional images. Third, we hypothesize that emotion-related brain responses to negative (-neutral) and positive (-neutral) images will predict substance use intentions in early adolescence. Fourth, as an exploratory analysis, if these hypotheses are supported, we will test whether there is a significant statistical mediation (or

indirect effect) from maternal alcohol use to adolescent substance use intentions through adolescent emotion-realted neural responses.

Method

Participants

Participants were recruited from a larger longitudinal study of adolescent emotion development and substance use (N = 249) which included adolescents between the ages of 12-14 and their mothers (Chaplin et al., 2019). Eighty-two adolescents within this study completed an MRI scan. Of these subjects, eight were excluded from the present analyses for excessive motion during the scan. These eight participants did not differ from the final sample on maternal alcohol use (number of days), adolescent substance use intentions, age, or race and ethnicity, although there were more boys than girls excluded. Four participants were missing parent data and were also excluded from the analysis, resulting in a final sample of 70 participants (35 female, mean age = 12.67, SD = 0.74). Adolescents were largely substance use naïve with 80% reporting no prior use (91% used less than two times). Families were recruited for the larger study through mailings to households in a suburban area in the mid-Atlantic United States. Inclusion criteria consisted of IQ >=80 for adolescent (on Wechsler Abbreviated Scale of Intelligence), adequate English proficiency to complete questionnaires for adolescent and caregiver, and MRI-safe for adolescent (e.g., no metal in body). Exclusion criteria were history of prenatal substance exposure, psychotic disorder, congenital brain defect, or traumatic brain injury for the adolescent.

The sample (which was collected from 2013-2015) was similar to the local community in race, ethnicity, and income, although attention should be paid to the fact that the sample consisted largely of upper-middle class White families in the suburban mid-Atlantic United States. Of the 70 adolescents included in the analysis, 74.3% identified as non-Hispanic White (n = 52), 8.6% identified as Hispanic White (n = 6), 4.3% identified as Asian (n = 3), 1.4% identified as Black/African American (n = 1), 8.6% identified as more than one race (n = 6), and 2.8% did not disclose their racial identity (n = 2). The majority of families (~20%) reported a household income greater than $100,000 per year, and most (~93%) of the mothers were married (~6% were separated/divorced).

Procedure

The present paper focused on assessments from the baseline time point. As part of their enrollment in the larger study, participants completed a baseline behavioral session during which adolescents and their mothers completed questionnaires and interviews to provide information about parenting

behaviors, emotion functioning, psychopathology, and substance use. They then completed a baseline MRI session approximately 2–4 weeks later. Study procedures were approved by the University Institutional Review Board. Mothers provided written consent and adolescents provided written assent to participate in the study prior to data collection.

Measures

Maternal Alcohol Use. Mothers completed the Addiction Severity Index (ASI) interview in which they reported their alcohol use over the previous thirty days. Interviews were conducted by trained research assistants during the baseline session. To measure alcohol consumption, we used an item asking for the number of days that a mother has drank alcohol in the 30 days prior to their baseline session. None of the mothers included in this study met criteria for Alcohol Abuse or Dependence (now Alcohol Use Disorder in DSM-5) based on completion of the Structured Diagnostic Interview for DSM-IV (SCID-IV) also at the baseline timepoint.

Maternal Depressive Symptoms. Mothers completed the Center for Epidemiological Studies Depression Scale (CES-D) (Radloff, 1977) to provide information about the occurrence of depressive symptoms during the week prior to their baseline session.

Adolescent Substance Use Intentions. Adolescents completed a questionnaire on intentions to use substances in the future. Adolescents were asked, "Do you think you would drink alcohol, smoke cigarettes, or use drugs when you are grown-up?" Adolescents responded with "Yes," "No," or "Maybe." This approach of measuring substance use intentions is the same as that used by Tildesley and Andrews (2008). We chose to combine "Yes" and "Maybe" responses to form a dichotomous outcome variable.

MRI Data Acquisition

Adolescents completed a 60-min MRI scan, which included three functional scans (emotion task and two others) and a T1-weighted structural scan. Scans were acquired on a Siemens 3T Allegra MR scanner with a single-channel birdcage head coil, which is standardly used with the Siemens 3T Allegra. During the emotion task, adolescents were shown positive, negative, and neutral images selected from the International Affective Picture System (IAPS; Lang et al., 2008). We used negative IAPS images that McRae et al. (2012) previously found to be developmentally appropriate while eliciting negative emotion. Neutral and positive images were selected from the IAPS database to match subject type, color, and luminesce. These images were

presented to adolescents during the MRI using *Presentation* software, rear-projected onto a screen, and viewed through a mirror mounted to the birdcage head coil. IAPS pictures were presented using an event-related design in a pseudo-randomized order, with trial order and timing determined with Optseq2 (Dale, 1999). A total of 81 trials (27 negative, 27 positive, 27 neutral) were presented across 3 runs of approximately 6.5 minutes each, with 27 trials per run and a balanced number of trial types per run. Each trial consisted of viewing a picture (4 s), youth rating their intensity of negative emotion (2 s) and positive emotion (2 s) on a scale from 1 to 4 using a button box, and an inter-trial interval period (viewing crosshairs) jittered between 2 s and 12 s.

MRI Preprocessing and Analysis

Preprocessing. FSL 5.0 (FMRIB's Software Library) (Jenkinson et al., 2012) was used to analyze each adolescent's blood-oxygen-level-dependent (BOLD) signal responses to emotional stimuli during the fMRI scan. Data were motion corrected, slice-timing corrected, and B0 unwarped. Runs with motion greater than 3 mm in any direction for one TR were excluded. Data were smoothed with a 6 mm FWHM Gaussian kernel, and a highpass temporal filter of 1/96 Hz was applied to remove frequency drifts in MR signal. Data were co-registered to each adolescent's MPRAGE image and then to the Montreal Neurological Institute (MNI) template. For the first level analyses, FILM (FMRIB's Improved Linear Model) was used, and regressors for the onset and duration of events of interest were convolved with a double gamma hemodynamic response function to create explanatory variables. For remaining runs with motion greater than 1.5 mm (< 3 mm) for one TR in any direction, FSL's motion outlier function was run, and additional motion confounds were included in first-level analyses. Coefficient of parameter estimate (COPE) parameters for explanatory values were used to create contrasts of interest: negative > neutral and positive > neutral.

ROI Analysis. Regions of interest (ROI) analyses were conducted using masks of the bilateral amygdala, bilateral ACC, and vmPFC. Masks of the amygdala were derived from the Harvard Oxford Subcortical Atlas. To improve accuracy of defined cortical regions, we used Neurosynth to create masks of the bilateral ACC and vmPFC by searching "acc" and "vmpfc" and thresholding the resulting map at Z = 5, consistent with (Chen et al., 2022). Neurosynth employs a metanalytic technique to produce representative maps of locations most consistently labeled as the ROI (Yarkoni et al., 2011). For coordinates of these masks, see Figure 1. As this approach can occasionally result in functionally-related regions outside of the ROI, we multiplied each mask by binarized cortical masks (Cingulate Cortex for ACC; Frontal Cortex for

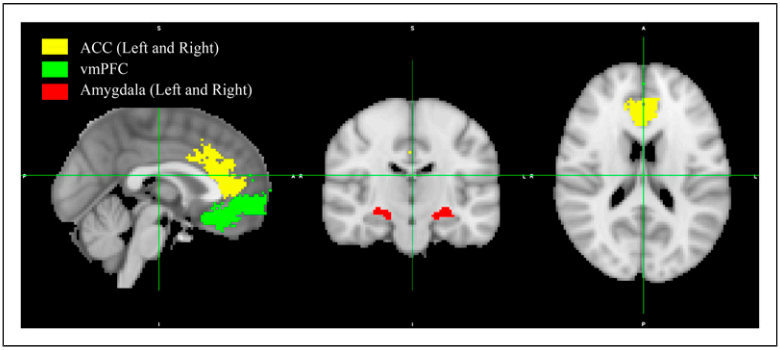

Figure 1. Masks of Region of Interests. *Note:* vmPFC = ventromedial prefrontal cortex, ACC = anterior cingulate cortex. Peak coordinates were Left ACC = (−2, −14, 10), Right ACC = (2, 34, 23), vmPFC = (−2, −14, 10), Left Amygdala = (−28, −2, −20), Right Amygdala (26, −2, −18).

vmPFC) and applied a threshold of $Z > 5$. The resulting masks can be seen in Figure 1.

Analyses

First, we conducted a binary logistic regression to test our hypothesis that greater maternal alcohol consumption would predict adolescent substance use intentions. Second, to evaluate whether maternal alcohol consumption was predictive of adolescent emotion-related brain function, we ran separate regression analyses that were FDR-corrected within each condition. This resulted in 10 regressions total across the two conditions (positive > neutral; negative > neutral) and five ROIs (vmPFC, left amygdala, right amygdala, left ACC, right ACC). Third, to test whether adolescent emotion-related brain function would predict adolescent substance use intentions, we ran separate binary logistic regression analyses that were FDR-corrected within each condition. This again resulted in 10 regressions total across the two conditions and five ROIs. All analyses were conducted using SPSS. Lastly, if all the above hypotheses were supported for a particular ROI/condition, we would test whether adolescent neural emotion reactivity statistically mediated the relationship between maternal alcohol use and adolescent substance use intentions using PROCESS macro in SPSS. For significant regressions, we report the effect size as r_{sp} (semi-partial correlation coefficient). Semi-partial correlations can be interpreted using Cohen's lower bound cutoffs of 0.1, 0.3, and 0.5 representing small, medium, and large effect sizes, respectively.

Results

Preliminary Results

We examined descriptive statistics (range, mean, standard deviation, skewness) for mothers' alcohol use, adolescent substance use intentions, and ROI activation, which are shown in Table 1. Skewness values were deemed appropriate (< 2) for all variables. Maternal alcohol use ranged from zero days of use to thirty days of use in the thirty days prior to assessment ($M = 6.50$, $SD = 8.41$) with 24.3% of parents reporting no alcohol use. In response to the item about intentions for later substance use, 60.8% of adolescents responded "No" and 39.2% responded "Maybe" or "Yes." Plots of standardized residuals and predicted values were examined for each regression model to assess for outliers.

Covariates

We considered including adolescent biological sex, adolescent psychiatric medication usage on the MRI scan day, and maternal depressive symptoms as covariates in the analyses if they were significantly associated with ROI activation or adolescents' intentions to use substances. Correlations between adolescent sex, maternal depressive symptoms, and other variables of interest

Table 1. Descriptive Statistics of Parental Alcohol Use, Adolescent Substance Use Intentions, and Adolescent Emotion-Related Brain Function Variables ($N = 70$).

Variable	Mean	SD	Minimum	Maximum	Skewness
Number of Parent alcohol use days in past 30 Days	6.49	8.41	0	30	1.69
Adolescent substance use intentions	0.40	0.49	0	1	0.42
vmPFC (NEG > NEU)	3.35	13.36	−24.63	56.36	1.08
vmPFC (POS > NEU)	5.02	11.05	−25.45	28.11	−0.51
Left ACC (NEG > NEU)	0.36	14.39	−34.34	34.40	0.01
Left ACC (POS > NEU)	−1.50	13.04	−35.36	26.18	−0.25
Right ACC (NEG > NEU)	0.03	11.24	−30.69	24.04	−0.11
Right ACC (POS > NEU)	−1.84	10.42	−28.96	20.31	−0.10
Left amygdala (NEG > NEU)	1.66	10.88	−42.48	28.18	−1.01
Left amygdala (POS > NEU)	1.41	8.45	−26.89	23.01	−0.62
Right amygdala (NEG > NEU)	1.00	10.83	−43.89	36.30	−0.62
Right amygdala (POS > NEU)	0.29	7.22	−22.31	15.89	−0.62

Note: vmPFC = ventromedial prefrontal cortex, ACC = anterior cingulate cortex, NEG > NEU = contrast representing response to negative (-neutral) emotional images, POS > NEU = contrast representing response to positive (-neutral) emotional images.

were not significant. Adolescent psychiatric medication use was significantly correlated with activation in the vmPFC for the positive (-neutral) contrast ($r = -.24$, $p < .05$) and in the bilateral amygdala for the negative (-neutral) contrast (r (left amygdala) $= -.31$, $p < .01$; r (right amygdala) $= -.29$, $p < .05$). Given these significant associations, psychiatric medication use was included as a covariate in all models with ROI activation as outcomes.

Hypothesis 1: Parental Alcohol Use and Adolescent Substance Use Intentions

A binary logistic regression assessing maternal alcohol use predicting adolescent substance use intentions was significant, X^2 (1) = 4.33, p = .037. Higher maternal alcohol consumption predicted greater odds of adolescents reporting intentions to use substances, B = .06, *Wald's* Z = 3.94, p = .047. Although this effect was significant, it was small, OR = 1.06, 95% CI [1.001, 1.131]. Based on the odds ratio derived from the model, we conclude that the odds of adolescents endorsing an intention to use substances increased by 1.06 for every additional day that a mother reported drinking alcohol in the 30 days prior to assessment.

Hypothesis 2a: Parental Alcohol Use and Adolescent Positive Emotion-Related Brain Function

Multiple regression analyses covarying for psychiatric medication use indicated that maternal alcohol use significantly predicted decreased functional activation in the vmPFC for the positive (-neutral) contrast, $B = -.44$, t (2, 67) $= -3.00$, $p_{FDR\text{-}corrected} = .02$, $r_{sp} = -.33$ (medium effect size). This model was significant overall, F (2, 67) = 6.88, $p_{FDR\text{-}corrected} = .01$, *Adjusted* $R^2 = .17$, and accounted for 17% of the variance in functional activation in the vmPFC in response to positive emotional images compared to neutral images (see Table 2).

Maternal alcohol use also significantly predicted decreased functional activation for the positive (-neutral) contrast in the left ACC, $B = -.44$, t (2, 67) $= -2.40$, $p_{\text{FDR-corrected}} = .03$, $r_{sp} = -.28$ (medium effect size), and in the right ACC, $B = -.37$, t (2, 67) $= -2.58$, $p_{FDR\text{-}corrected} = .03$, $r_{sp} = -.30$ (medium effect size). These models accounted for 8% and 9% of the variance in emotion-related brain function, respectively (see Table 2).

Maternal alcohol use did not significantly predict functional activation to positive (-neutral) emotional images in the left amygdala, $B = -.11$, t (2, 67) $= -.93$, $p_{\text{FDR-corrected}} = .35$, $r_{sp} = -.11$ or right amygdala, $B = -.16$, t (2, 67) $= -1.61$, $p_{\text{FDR-corrected}} = .14$, $r_{sp} = -.19$ (see Table 2).

Hypothesis 2b: Parental Alcohol Use and Adolescent Negative Emotion-Related Brain Function

Maternal alcohol use did not significantly predict activation for the negative (-neutral) contrast in any of the ROIs (see Table 3).

Hypothesis 3: Adolescent Emotion-Related Brain Function and Substance Use Intentions

There were no significant relationships between adolescent emotion-related brain activation and substance use intentions. Given that only the first portion of our proposed mediation model was significant, it was not appropriate to formally test the mediation model.

Table 2. Results of Adolescent Emotion-Related Brain Function (Positive – Neutral) Regressed on Maternal Alcohol Use, Covarying for Psychiatric Medication Use.

	Overall model			Coefficients (maternal alcohol use)				
Outcome	$F(2, 67)$	$p_{(FDR)}$	R^2	B	SE	t	$p_{(FDR)}$	r_{sp}
vmPFC	6.88	.01*	.17	−.44	.15	−3.0	.02*	−.33
Left ACC	2.95	.07	.08	−.44	.18	−2.40	.03*	−.28
Right ACC	3.37	.07	.09	−.37	.15	−2.58	.03*	−.30
Left amygdala	1.24	.30	.04	−.11	.12	−.93	.35	−.11
Right amygdala	2.95	.07	.08	−.16	.10	−1.61	.14	−.19

Note: vmPFC = ventromedial prefrontal cortex, ACC = anterior cingulate cortex. Reported p-values were FDR-corrected (k = 5). * indicates $p < .05$.

Table 3. Results of Adolescent Emotion-Related Brain Function (Negative – Neutral) Regressed on Maternal Alcohol Use, Covarying for Psychiatric Medication Use.

	Overall model			Coefficients (parental alcohol use)				
Outcome	$F(2, 67)$	$p_{(FDR)}$	R^2	B	SE	t	$p_{(FDR)}$	r_{sp}
vmPFC	2.18	.20	.03	−.30	.19	−1.59	.52	−.19
Left ACC	.87	.42	0	−.25	.21	−1.22	.52	−.15
Right ACC	.95	.42	0	−.17	.16	−1.02	.52	−.12
Left amygdala	3.94	.10	.08	−.11	.15	−.72	.59	−.08
Right amygdala	3.31	.10	.09	−.08	.15	−.56	.59	−.07

Note: vmPFC = ventromedial prefrontal cortex, ACC = anterior cingulate cortex. Reported p-values were FDR-corrected (k = 5). * indicates $p < .05$.

Discussion

The present study sought to add to a limited literature examining parental sub-clinical alcohol use, adolescent neural emotion reactivity, and substance use intentions in early adolescents. Notably, it is the first to examine associations between parental sub-clinical alcohol use and adolescent emotional functioning. Here we examined effects of parental alcohol use in a sample of mothers, who may provide an important context for alcohol socialization during adolescence. We found that alcohol use in mothers significantly predicted adolescents' intentions to use substances. Further, we found that higher maternal alcohol use predicted adolescents' *blunted* neural response to positive (-neutral) emotional images in the vmPFC and bilateral ACC. Unexpectedly, we did not find a significant association between maternal alcohol use and neural responses to negative (-neutral) emotional images. In addition, adolescent neural response to emotional images did not predict adolescent substance use intentions. Overall, this suggests that parental drinking behaviors may be related to adolescents' intentions to use substances and positive emotional processing separately, but that neural emotion reactivity was not associated with intentions for use in this study sample.

Parental Alcohol Use and Adolescent Substance Use Intentions

As hypothesized, our results indicated that alcohol consumption by mothers predicted adolescent substance use intentions with a small effect size. Although this effect size is small, it is consistent with prior studies that have found that parental alcohol use is correlated with adolescent substance use (Chassin et al., 1996; Rossow et al., 2016; Ryan et al., 2010) and a few emerging studies that have found this for adolescent substance use intentions (Kam et al., 2017; Tildesley & Andrews, 2008).

This finding suggests that parents' sub-clinical alcohol use during early adolescence may impact their child's thoughts about using substances later in life. Because of their parents' alcohol use, early adolescents may develop more positive thoughts about substances and incorporate plans for future substance use into their developing identities. This could lead them to initiate and escalate substance use as they develop into middle and later adolescence (Barkin et al., 2002; Montes et al., 2019). This process may occur as a result of children observing their parents using alcohol and thinking they will also use substances as adults (i.e. modeling). Seeing their parent use alcohol can also normalize substance use for adolescents and convey positive attitudes toward substance use (Miller et al., 2013; Van Der Vorst et al., 2006). This study examined parental drinking in mothers, which is important because mothers in the U.S. spend more time than fathers with their kids on average (Schaeffer & Aragão, 2023; Wang, 2013). However, focusing only on mothers is also a limit

of the study, and future work should examine whether the same patterns hold for fathers.

Taken together with findings from previous studies, our finding of mothers' drinking predicting adolescent substance use intentions suggests a need for targeted prevention of substance use behaviors for children whose parents drink alcohol more frequently, even if their parent does not have an AUD. In a systematic review and metanalysis of parenting factors associated with adolescent alcohol use, Yap et al. (2017) found that parental monitoring, parent-child relationship quality, parental support, and parental involvement most consistently emerged as parenting factors that reduce the likelihood of adolescents using alcohol. These specific parenting behaviors may serve as useful areas to focus on when working with parents who use alcohol. In addition, prior work has suggested encouraging parents to provide specific cautionary messages about substance use and to avoid using substances in front of their children (Cox et al., 2018).

Parental Alcohol Use and Adolescent Emotion-Related Brain Function

A unique aim of this study was to examine associations between sub-clinical parental alcohol use and adolescent neural activation in response to positive and negative emotional images. We found that more frequent alcohol use in mothers significantly predicted blunted activation in adolescents in response to positive (-neutral) emotional images in the vmPFC and bilateral ACC. Notably, maternal alcohol use did not predict youth's neural responses to negative (-neutral) emotional stimuli. Thus, the effect of parental alcohol use may be particular to youth's positive emotional responses.

The observed blunted reactivity to positive emotional stimuli is consistent with findings by Cservenka et al. (2014) who found blunted responses to positive images in the STG for children of a parent with AUD. Our results extend this finding to additional regions involved in emotion processing and demonstrate that neural reactivity to positive emotional stimuli correlated with parental drinking even when that drinking was at a sub-clinical level. The vmPFC and ACC have been implicated in reward processing and emotion regulation (Hiser & Koenigs, 2018; Kim et al., 2011; Rogers et al., 2004; Stevens et al., 2011; Šimić et al., 2021). Findings of blunted activation to positive emotion in these regions could imply that greater parental alcohol use predicts blunted reward sensitivity in youth, which is a pattern that has been observed in studies looking at children with parents with AUD (Kirk-Provencher et al., 2024; Martz et al., 2022).

There are several ways by which parents' alcohol use could impact their child's neural reactivity to positive/rewarding stimuli. First, parents who drink alcohol may have altered positive emotional functioning themselves. There is some emerging evidence that neural response to generally rewarding stimuli

(i.e., money) is related to alcohol reward sensitivity (Radoman et al., 2021). Parents who drink alcohol more frequently may have patterns of positive emotion reactivity/reward sensitivity that influence their drinking behavior and that they pass onto their children via modeling or genetic predispositions. For example, variations of genes encoding D1 and D2 dopamine receptors have been implicated in reward processing and associated with alcohol use (Baker et al., 2019; Zink, 2016). Second, alcohol consumption could influence parenting behaviors which could then impact child positive emotional reactivity (Kopala-Sibley et al., 2020). However, the current study did not assess parenting behaviors, and associations between negative parenting practices and parental alcohol use have been observed primarily in parents with AUD (Slesnick et al., 2014; Solis et al., 2012).

Given a cross-sectional data analysis, we are unable to conclusively ascertain that more frequent drinking in mothers led to adolescents' blunted neural responses to positive emotional stimuli; however, should further studies observe similar findings, there could be implications of parental drinking leading to youth showing blunted neural responses to positive/rewarding stimuli. In particular, blunted neural responses to positive/rewarding stimuli have been shown as a risk factor for substance use in adolescence (Aloi et al., 2018; Leiker et al., 2019; McQuaid et al., 2022), although we did not find an association with substance use intentions in the present study of early adolescents. Future longitudinal studies should examine parental drinking, adolescent neural emotional reactivity, and the development of more intensive and risky substance and alcohol use from early to later adolescence.

Adolescent Emotion-Related Brain Function and Substance Use Intentions

Unexpectedly, we did not find any associations between adolescent neural responses to positive or negative emotional images and adolescents' intentions to use substances. There are several reasons why we may not have found significant relationships between adolescent neural emotion reactivity and substance use intentions. First, much of the existing literature on adolescent neural emotion reactivity and substance use has been completed cross-sectionally with adolescents who have already begun using substances, and observations of neural activation could be the result of substance use (Heitzeg et al., 2008; Jones et al., 2023; Leiker et al., 2019). A few studies to date have sought to address this by using longitudinal designs with substance naïve youth, with mixed results (Gonçalves et al., 2022; McQuaid et al., 2022). Also, our study was the first to our knowledge to look at substance use intentions, as opposed to substance use behaviors. While substance use intentions are a useful proxy for later substance use (Andrews et al., 2003;

Hamilton et al., 2022; Webb et al., 1996), we recognize that substance use intentions are unlikely to perfectly predict later substance use, and therefore we may not observe the same associations with intentions as we do with behaviors.

Limitations

We believe including substance use intentions as opposed to substance use to be a unique addition to the literature that may help us identify how early adolescents' thoughts about substances are shaped by their parents' alcohol use. However, as mentioned above, we recognize that substance use intentions are a proxy measure for later use. Further research may study substance use longitudinally to formally evaluate impacts of parent drinking on substance use intentions and later use. Another limit of our study is that we examined parental drinking only in mothers. While mothers are an important group to study given that they tend to spend more time with their children on average and have been historically understudied in alcohol research, it would be important for future research to examine impacts of parental sub-clinical drinking for fathers as well as mothers. In addition, our measure of maternal alcohol use was reported by the mothers, but we did not measure teen's perceptions of their mothers' use. Given that we cannot know whether the adolescents in this study were aware of/exposed to their parents' drinking, we cannot conclude that the observed effect of parental drinking on adolescent substance use intentions can be explained by modeling of drinking behaviors or perceived pro-substance attitudes; however, future work may choose to explore this. With regards to our sample, we are limited by a fairly small sample that is primarily White and upper middle class, which may limit generalizability. Finally, while listwise deletion of participants with excessive motion is necessary to maintain reliable neuroimaging data, it did reduce our sample size and exclude some demographics more than others. In this case, we excluded more boys than girls for motion. Given that adolescent sex was not significantly associated with study variables, we do not anticipate that this significantly influenced the results.

Conclusion

Much attention has been paid to the impacts of parental AUD on adolescent substance use and some studies have also shown that sub-clinical parental drinking impacts adolescent substance use and substance use intentions. The present study adds to a limited literature showing that children are more likely to endorse an intention to use substances if their mothers drink more alcohol. This information is useful when working with children whose parents drink alcohol regularly, even at sub-clinical levels, to better understand their risk for

later substance use and substance-related difficulties. We also explored associations between frequency of alcohol use by mothers and adolescent neural activation to positive and negative emotional images. We found a significant association between more frequent maternal alcohol use and blunted neural reactivity to positive emotional stimuli in the vmPFC and bilateral ACC. This finding suggests that higher parental drinking levels may lead youth to show blunted response to positive cues, a pattern that has also been observed in prior studies of parental drinking with clinical samples of parents with AUD. Pending replication and further research, this finding could suggest a need for targeted prevention for youth whose parents drink alcohol regularly, even at sub-clinical levels, and may inform such prevention programs by focusing on remediating blunted positive emotion reactivity.

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