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Alcohol use in young adults associated with cortical gyrification

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ABSTRACT

Background: Young adulthood has the highest rates of alcohol use and high-risk drinking behavior. This period is also a critical neurodevelopmental stage, with neural insults having a profound neurotoxic effect on the brain. Cortical gyrification is thought, in part, to reflect early brain maturation (e.g., hypogyrification in fetal alcohol syndrome). There is also evidence that cortical gyrification is sensitive to later-life events (e.g., fluctuations in malnutrition in young adults). However, no study has examined how alcohol use in young adulthood is associated with cortical gyrification.

Methods: We examined the associations between cortical gyrification with lifetime alcohol use and past year hangover symptoms in young adults ($N = 78$).

Results: Lifetime alcohol use was associated with hypogyria in multiple cortical regions ($rs \leq -.27$, $ps \leq .0159$; right orbitofrontal, right temporal pole, and left lateral occipital). Further, past year hangover symptoms were associated with hypogyria ($rs \leq -.27$, $ps \leq .0034$), overlapping with lifetime alcohol use (right orbitofrontal and left lateral occipital). Hangover symptoms were also uniquely associated with hypogyria of other cortical regions ($rs \leq -.30$, $ps \leq .0002$; right parahippocampal gyrus, left inferior temporal/parahippocampal gyrus and right anterior insula).

Conclusions: Thus, results suggest that young adulthood is a critical period for targeted prevention and intervention, especially for individuals exhibiting heavy alcohol consumption and high-risk drinking behavior.

1. Introduction

Young adulthood has been associated with the highest alcohol use rates, with many young adults engaging in extreme patterns of drinking (Chen et al., 2004). Adolescence through young adulthood is also a critical neurodevelopmental stage in which the brain undergoes many maturational changes (Squeglia and Gray, 2016). Previous research has found evidence that alcohol use in young adulthood is associated with decreased cortical volume and thickness abnormalities (e.g., Weiland et al., 2014; Welch et al., 2013). Thus, young adulthood is a critical stage in which to examine the deleterious effects of alcohol use on cortical structure. In particular, cortical gyrification, the process through which the surface of the brain forms gyri and sulci, continues through young adulthood. Gyrification is critical in allowing greater surface area and gray matter volume to fit within the skull without compromising efficiency of white matter connections (White et al., 2010). Abnormal gyrification can thus result in inefficient neuronal connectivity and be a marker of abnormal neurodevelopment. However, to our knowledge, no previous study has examined whether and how alcohol use is associated with cortical gyrification. Hence, the current study examined associations between alcohol use in young adulthood with cortical gyrification.

Given that the brain undergoes significant neurodevelopmental changes from adolescence through young adulthood (White et al., 2010), it has been widely posited that alcohol use in adolescence (and potentially extending into late adolescence/young adulthood) has a greater neurotoxic effect on the brain than in later adulthood (Brown et al., 2008; Jacobus and Tapert, 2013). Consistent with this view, animal research has found greater deleterious effects of alcohol on the brain in adolescence than in adulthood (Brown et al., 2008; Squeglia et al., 2014a). In humans, longitudinal studies have found that heavier drinking in young adults is associated with greater volumetric decline in reward processing and cue-reactivity regions (Heikkinen et al., 2017; Meda et al., 2017, 2018), such as the bilateral orbitofrontal cortex, right insula, and bilateral parahippocampal gyrus (Heikkinen et al., 2017; Meda et al., 2017, 2018; Weiland et al., 2014; Welch et al., 2013). This

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is potentially consistent with functional task-based studies that have found alcohol use associated with reward learning deficits and increased cue-reactivity (e.g., Dager et al., 2013; Howse et al., 2018). At the same time, smaller bilateral orbitofrontal cortex volumes have been found to be predictive of drinking initiation in late adolescence/young adulthood (Weiland et al., 2014). Hence, cortical abnormalities are bidirectional and can be both a premorbid risk factor for drinking onset and a consequence of early alcohol use (Ewing et al., 2014; Weiland et al., 2014; Welch et al., 2013).

Although it has been argued that alcohol use, especially heavier drinking, has a great neurotoxic effect on the developing brain (Brown et al., 2008; Jacobus and Tapert, 2013), no study has examined how hangover symptoms are related to cortical structure. Hangover symptoms have been posited to be a more accurate marker of drinking quantity and to be more detrimental to the brain than total amount of alcohol consumed (Squeglia et al., 2014b). While research in this field is limited, evidence has implicated the involvement of inflammatory processes in the pathophysiology of hangovers (e.g., Palmer et al., 2019). Therefore, in addition to examining overall alcohol use, hangovers could potentially reflect neurotoxic effects of alcohol consumption and be associated with cortical structure.

Though studies have found cortical volume and thickness abnormalities associated with alcohol use, it is unclear how alcohol use is associated with cortical gyrification. Cortical gyrification arises from an altogether different process than volume and thickness (White et al., 2010), with previous research finding that maturational changes in cortical gyrification only partially overlapped with changes in volume and thickness (Klein et al., 2014), and that cortical gyrification is positively correlated with volume but negatively with thickness (Gautam et al., 2015). Additionally, cortical gyrification, in particular, is directly related to efficiency of white matter connectivity. The formation of gyri and sulci allows regions of greater connectivity to be drawn closer together, thus increasing the speed of action potentials from one region to another (Gautam et al., 2015; White et al., 2010). It has been consistently posited that cortical gyrification abnormalities, such as hypogyria (i.e., decreased gyrification), are an *in vivo* marker of underlying neural connectivity abnormalities (Dauvermann et al., 2012; Van Essen, 1997; White and Hilgetag, 2011). As such, it is important to examine the unique contributions of cortical gyrification with alcohol use.

Although multiple mechanistic theories have been proposed (see gyrification reviews: (Ronan and Fletcher, 2015; Striedter et al., 2015; Van Essen, 1997), much is still unknown regarding the mechanisms underlying cortical gyrification. What is known is that cortical gyrification abnormalities reflect primarily prenatal environmental insults (Hendrickson et al., 2017, 2018; Ronan and Fletcher, 2015) and are determined more by environmental than genetic factors (Zilles et al., 2013). For instance, multiple studies have found fetal alcohol syndrome (e.g., Hendrickson et al., 2017, 2018) and psychological disorders (e.g., Matsuda and Ohi, 2018; Schmitgen et al., 2019) to be associated with widespread cortical gyrification abnormalities.

There is also evidence that cortical gyrification is sensitive to later-life environmental factors and insults. Studies have found that previous long-term life experiences (e.g., years spent meditating in meditation practitioners; Luders et al., 2012) are correlated with cortical gyrification changes. For example, a recent study found that acutely ill and malnourished individuals with anorexia nervosa (n = 87) had widespread cortical hypogyria compared to healthy controls (n = 142; Bernardoni et al., 2018). After partial weight restoration, these individuals (n = 57) showed significantly increased gyrification, mainly overlapping with regions that had previously shown hypogyria. Further, after full recovery, there were no longer significant between-group differences in cortical gyrification (Bernardoni et al., 2018). These studies suggest that cortical gyrification may also be sensitive to long-term life experiences and later-life environmental factors.

In the current study, we examined whether alcohol use in young adulthood was associated with cortical gyrification. To examine predisposing/longstanding factors, we examined associations with lifetime alcohol use. To examine recent factors, we examined associations with current average monthly alcohol use and past year hangover symptoms. To our knowledge, this is the first study to examine associations between alcohol use and cortical gyrification in young adults (or at any age) and to examine how hangover symptoms are related to cortical structure.

2. Materials and methods

2.1. Participants

Participants were University of Missouri undergraduate students (N = 78; though recruitment was specifically targeted to undergraduate students, there were some participants where student status was not coded, so there is a possibility that a few non-student participants might have entered the study through word of mouth), who were about to celebrate their 21st birthday (on average, participants were 11 days from their 21st birthday). Exclusion criteria included: MRI contraindications (e.g., metal medical devices such as a pacemaker or sizeable metal from previous dental work that could result in a large imaging artifact; being claustrophobic), a history of head injury resulting in a loss of consciousness for over two minutes or taking prescribed medication (except birth control). Participants were instructed not to consume alcohol, illicit drugs, ibuprofen, or antihistamines for at least 24 h before each scanning session and to abstain from smoking for at least 30 min before each scanning session. Participants were 52.56 % female and 85.90 % White/Caucasian..

2.2. Materials

2.2.1. Lifetime alcohol use

The Lifetime Drinking History (Jacob, 1988) interview retrospectively assessed lifetime alcohol use patterns starting from when an individual began drinking regularly and ending with the individual's current drinking pattern. We calculated two key variables: drinking onset age and adjusted lifetime alcohol use. *Drinking onset age* was defined as the age at which each participant started drinking regularly. Since younger age has been associated with increased rates of alcohol-related problems (Squeglia and Gray, 2016) and alcohol dependence (e.g., Hingson et al., 2006), we reversed the direction of morphometric associations with this variable to reflect the relationship between younger age and alcohol-related problems. *Adjusted lifetime alcohol use* was calculated by summing the estimated total number of drinks across all drinking phases. Lifetime drinks greater than two standard deviations from the sample mean were winsorized to minimize the influence of outliers.

2.2.2. Current alcohol use

To examine whether recent alcohol use differed from lifetime alcohol use, in exploratory analyses, we also calculated current average monthly alcohol use using the Lifetime Drinking History (Jacob, 1988) interview. *Current average monthly alcohol use* was defined as the average number of drinks per month that the participant consumed based on the participant's current drinking phase.

2.2.3. Hangover symptoms

The 13-item self-report Hangover Symptoms Scale (Slutske et al., 2003) assessed past year hangover symptoms. Hangover symptoms were rated on a 5-point Likert scale. To create a more normally distributed variable as recommended by scale developers (Slutske et al., 2003), we dichotomized each symptom as to either having "never occurred" or "ever occurred" in the past year. Number of *past year hangover symptoms* was calculated by summing the 13 dichotomized items. Higher scores have been associated with increased drinking frequency and getting drunk (Slutske et al., 2003), and have been found

to predict occurrence of daily-life hangovers (Robertson et al., 2012).

2.3. MRI processing

MRI scans (see Supplemental Methods[1] for acquisition parameters and instructions) were processed using a well-validated surface-based approach (FreeSurfer 6.0.0; https://surfer.nmr.mgh.harvard.edu; full details in Supplemental Methods[1]). To process data for cortical gyrification, an outer smoothed surface tightly enveloping the pial surface was created (Schaer et al., 2008). Local gyrification index maps were smoothed using the default full-width half-maximum Gaussian kernel of 25 mm. MRI surface reconstructions were manually checked for inaccuracies and artifacts by JPYH.

Local Gyrification Index (see Supplemental Methods[1] for more details) was estimated by computing the ratio of surface area between a circular region of interest on the pial surface (i.e., buried cortex within the sulcal folds) with the surface area of its corresponding circular region of interest on the outer smoothed surface (i.e., visible cortex; Schaer et al., 2008).

2.4. Analyses

2.4.1. Whole-brain regional cortical gyrification analyses

General linear models were used to estimate whether alcohol use variables were correlated with local Gyrification Index across the whole brain. Following previous research and recommendations, gender and intracranial volume were included as covariates (e.g., Hendrickson et al., 2017). Analyses were not further smoothed because gyrification maps were previously smoothed during processing (Schaer et al., 2013). To account for analyses using both hemispheres, *p*-values were Bonferroni-corrected. Analyses were also corrected for multiple comparisons using Monte Carlo simulations set at 10,000 iterations, vertex-wise cluster-forming threshold of $p < .05$ (e.g., Schaer et al., 2013), and two-tailed cluster-wise P (CWP) threshold of $p < .05$ (e.g., Hagler Jr. et al., 2006).

In post-hoc analyses of significant gyrification clusters, we further examined whether there were also significant associations between alcohol use measures with cortical volume and thickness (see Supplemental Results[1]).

2.4.2. Multiple imputation analyses

Using Little's Missing Completely at Random Test (Little, 1988), data were determined to be missing at random for Lifetime Drinking History ($n = 12$) and Hangover Symptoms Scale ($n = 5$). Missing values were filled in using multiple imputation. Results were extremely similar for raw and imputed data; we report analyses with raw data (for imputed results, see Supplemental Figs. 1–4).

2.5. Procedure

Undergraduate students were recruited for a three-session study on extreme drinking in young adults. Participants came in, on average, 11 days prior to their 21st birthday and completed a structural scan and alcohol use measures; these are the data reported in the current manuscript (Hua et al., 2019; data collected on a subset of these participants after their 21st birthday will be reported elsewhere). Study procedures were in accordance with the ethical standards of the University of Missouri's Institutional Review Board and the latest version of the Declaration of Helsinki. All participants provided informed consent.

3. Results

3.1. Alcohol use descriptives and correlations

Average drinking onset age (Table 1) was similar to the national average in young adults (i.e., $M = 17.4$ years; Chen et al., 2004).

Table 1
Alcohol Use Variables Descriptive Statistics.

Variable	Mean (*SD*)	Range
Lifetime Drinking History		
Drinking Onset Age (years)[a]	17.48 (1.56)	13-20
Adjusted Lifetime Alcohol Use	1,137.17 (1272.65)	0-4,880[b]
Current Drinking		
Current Average Monthly Alcohol Use	39.16 (36.12)	0-198
Hangover Symptoms Scale		
Past Year Hangover Symptoms	6.32 (3.21)	0-12

[a] Three participants were nondrinkers.
[b] Lifetime drinks beyond two standard deviations of the mean were winsorized.

Table 2
Alcohol Use Variables Zero-Order Correlations.

Variables	1	2	3	4
Lifetime Drinking History				
1 Drinking Onset Age[a]	—			
2 Adjusted Lifetime Alcohol Use	.65***	—		
Current Drinking				
3 Current Average Monthly Alcohol Use	.40***	.75***	—	
Hangover Symptoms Scale				
4 Past Year Hangover Symptoms	.57***	.49***	.43***	—

[a] Drinking onset age was reversed scored.
*** $p < .001$.

Moreover, in the past year, participants experienced around one hangover symptom greater than the average number endorsed by a large sample of college students (Slutske et al., 2003). Based on hangover symptoms, our sample appeared to drink at least as heavily as a typical college student sample, consistent with this being an age associated with heaviest lifetime drinking. Further, alcohol use variables were significantly correlated with each other (Table 2). Three participants in the current study were nondrinkers, and analyses excluding these three nondrinkers were very similar (see Supplement Figs. 5–7; note that when the three nondrinkers were excluded, younger age of drinking was not associated with hypogyria of the left lateral occipital).

Additionally, associations between alcohol use and cortical gyrification could be confounded by other drug use such as cigarettes, cannabis, or other illicit drugs (i.e., used either hallucinogens, cocaine, amphetamines, or sedatives more than five times in their lifetime), or by a psychiatric diagnosis. As such, we also examined associations between these possible confounding variables with drinking variables and with gyrification and also included these variables as covariates in our analyses (see Supplemental Results[1]). Note that results using substance use and psychiatric diagnosis variables should be interpreted with caution, as data on these variables were missing for a number of participants.

3.2. Lifetime alcohol use associated with cortical hypogyria

Lifetime alcohol use was associated with cortical gyrification (Table 3 and Fig. 1). Specifically, both younger age of regular drinking onset and greater lifetime alcohol use were associated with hypogyria of a right orbitofrontal region, Additionally, younger age of regular drinking onset was associated with hypogyria in a left lateral occipital region belonging to the visual network (Yeo et al., 2011). Further, greater lifetime alcohol use was associated with hypogyria of a right temporal pole/inferior temporal gyrus region.

3.3. Current alcohol use associated with cortical hypogyria

In exploratory analyses, current average monthly alcohol use was associated with cortical hypogyria of the same right orbitofrontal

Table 3
Lifetime and Current Alcohol Use Associations with Local Gyrification Index.

		Cluster Size			MNI Peak Coordinates		
Variable	Anatomical Region	(mm^2)	*r*	CWP [90 % CI]	X	Y	Z
Cortical Hypogyria							
Drinking Onset Age[a]	Right Orbitofrontal[b]	611.77	−.27	.0159 [.0138, .0183]	22.2	11.9	−19.5
	Left Lateral Occipital[b]	802.46	−.28	.0008 [.0004, .0014]	−42.9	−74.2	−5.5
Adjusted Lifetime Alcohol Use	Right Orbitofrontal[b]	1,199.81	−.32	.0002 [.0000, .0004]	20.1	15.2	−21.7
	Right Temporal Pole[c]	1,442.10	−.33	.0002 [.0000, .0004]	37.2	0.7	−40.1
Current Average Monthly Alcohol Use	Right Orbitofrontal[b]	643.07	−.28	.0010 [.0082, .0118]	19.35	12.80	−22.62

Note. CWP [90 % CI] = cluster wise probability after correction for multiple comparisons [90 % confidence intervals]; MNI = Montreal Neurological Institute.
[a] Drinking onset age variable was reverse scored.
[b] Anatomical region corresponding to the Desikan-Killiany atlas (Desikan et al., 2006).
[c] Anatomical region corresponding to Olson et al. (Olson et al., 2007).

region that was associated with lifetime alcohol use variables (Table 3 and Fig. 2).

3.4. Hangover symptoms associated with cortical hypogyria

Greater number of past year hangover symptoms was associated with hypogyria in multiple regions (Table 4 and Fig. 3). Specifically, past year hangover symptoms were associated with cortical hypogyria of the same right orbitofrontal region and left lateral occipital region that were both associated with hypogyria for lifetime alcohol use. Cortical hypogyria of the right orbitofrontal region slightly overlapped and was adjacent to the region of hypogyria associated with current alcohol use. Moreover, past year hangover symptoms were also uniquely associated with cortical hypogyria of the right parahippocampal gyrus, left inferior temporal/parahippocampal gyrus, and right anterior insula.

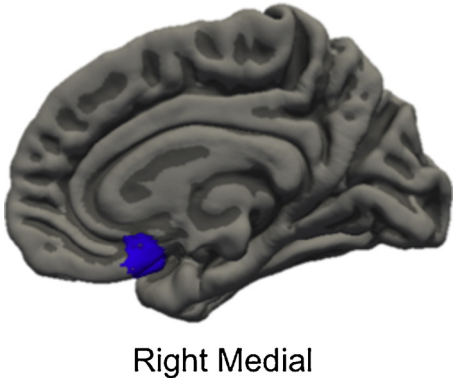
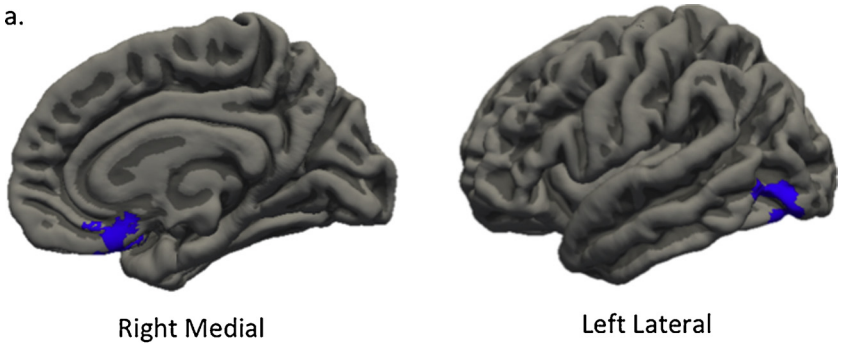


Fig. 2. Current alcohol use associated with cortical gyrification. Greater current average monthly alcohol use was associated with hypogyria of the right orbitofrontal gyrus (in right medial view).



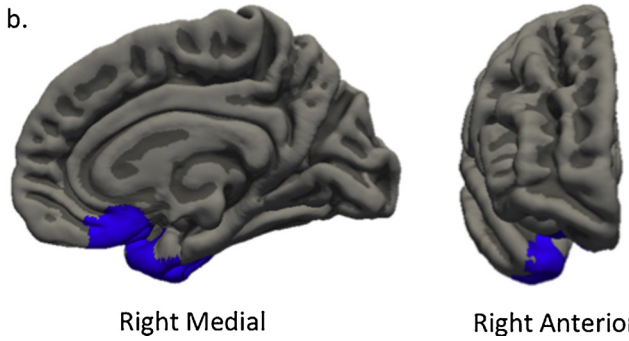


Fig. 1. Lifetime alcohol use associated with cortical gyrification. a.) Younger age of drinking associated with hypogyria of right orbitofrontal (in right medial view) and left lateral occipital regions (in left lateral view); b.) Greater lifetime alcohol use associated with hypogyria of right orbitofrontal (in right medial view) and right temporal pole (in right medial and anterior views).

Table 4
Hangover Symptoms Associations with Local Gyrification Index.

		Cluster Size			MNI Peak Coordinates		
Variable	Anatomical Region	(mm^2)	*r*	CWP [90 % CI]	X	Y	Z
Cortical Hypogyria							
Past Year Hangover Symptoms	Right Orbitofrontal[a]	760.59	−.27	.0034 [.0024, .0044]	9.7	31.5	−20.3
	Right Parahippocampal Gyrus[a]	1,937.29	−.32	.0002 [.0000, .0004]	23.3	−21.3	−22.3
	Left Temporal Pole[b]	1,944.03	−.30	.0002 [.0000, .0004]	−38.7	−3.9	−42.4
	Right Insula[a]	1,150.78	−.30	.0002 [.0000, .0004]	36.9	0.5	4.5
	Left Lateral Occipital[a]	894.28	−.27	.0004 [.0000, .0008]	−28.6	−93.5	−6.4

Note. CWP [90 % CI] = cluster wise probability after correction for multiple comparisons [90 % confidence intervals]; MNI = Montreal Neurological Institute.
[a] Anatomical region corresponding to the Desikan-Killiany atlas (Desikan et al., 2006).
[b] Anatomical region corresponding to Olson et al. (Olson et al., 2007).

4. Discussion

Young adulthood is a critical period in which to examine the effect of alcohol use on the brain, with recent studies finding evidence that cortical gyrification is sensitive to both long-term life experiences (Luders et al., 2012) and later-life events (e.g., Bernardoni et al., 2018). The current study found novel evidence that alcohol use in young adults was associated with cortical gyrification. These results suggest that altered cortical gyrification is associated with alcohol use in young adulthood. They also suggest that alcohol use could potentially alter cortical gyrification, which could, in turn, further increase the likelihood of harmful alcohol use.

Altered cortical gyrification has been proposed as an *in vivo* marker of neuronal connectivity with hypogyria reflecting aberrant neuronal connectivity (Dauvermann et al., 2012; Striedter et al., 2015). Although much is unknown regarding the underlying mechanism, gyrification allows regions of greater connectivity to be drawn closer together; thus, directly increasing the speed of action potentials and efficiency of white matter connectivity (Gautam et al., 2015; White et al., 2010). As such, hypogyria is thought to result in decreased neural connectivity and efficiency of processing.

Specifically in the current study, lifetime alcohol use was associated with cortical gyrification. Both younger age of drinking and greater lifetime alcohol use were associated with hypogyria of the same right orbitofrontal region. Younger drinking onset age was associated with hypogyria in the left lateral occipital cortex, and greater lifetime alcohol use was associated with hypogyria of the right temporal pole/inferior temporal gyrus. Additionally, current alcohol use was associated with hypogyria of the right orbitofrontal cortex. Previous research has consistently found the orbitofrontal cortex to be strongly associated with alcohol use (Moorman, 2018), with both cross-sectional and longitudinal studies finding decreased cortical volume of the orbitofrontal cortex in young adult heavy drinkers (e.g., Heikkinen et al., 2017; Meda et al., 2017). Furthermore, these findings are also consistent with previous cross-sectional and longitudinal research finding decreased cortical volume of the left occipital gyrus (Meda et al., 2017) and temporal pole/inferior temporal gyrus in adolescent and young adult heavy drinkers (Makris et al., 2008; Squeglia et al., 2014c). As cortical gyrification is considered a marker of underlying neural connectivity, decreased cortical gyrification of these brain regions could be a reflection of the decreased efficiency associated with heavy alcohol use in alcohol-related processes, such as reward processing and cue-reactivity (Hanlon et al., 2014; Moorman, 2018; Schacht et al., 2013).

The current study also examined past year hangover symptoms because these symptoms have been posited to be a more accurate marker of the effects of alcohol than amount of alcohol consumed (Squeglia et al., 2014b) and because inflammatory processes associated with hangovers have been thought to underlie the neurotoxic effects of alcohol consumption (Palmer et al., 2019). Interestingly, cortical gyrification patterns associated with hangover symptoms overlapped with

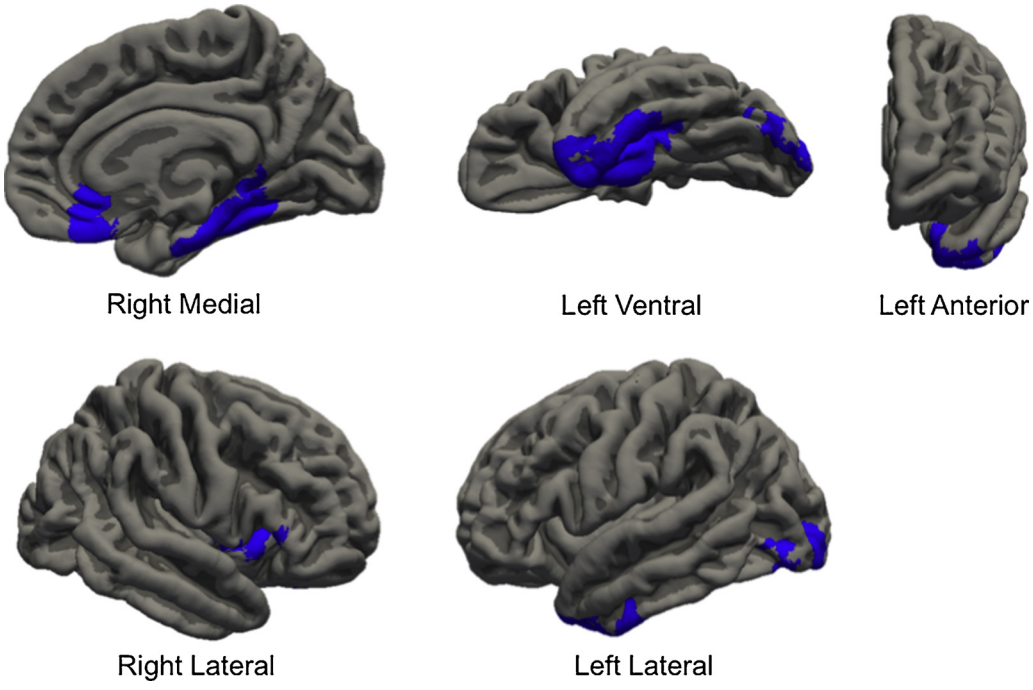


Fig. 3. Hangover symptoms associated with cortical gyrification. Greater number of past year hangover symptoms associated with hypogyria in right orbitofrontal (in right medial view), right parahippocampal gyrus (in right medial view), left temporal pole (in left ventral, lateral, and anterior views), right insula (in right lateral view), and left lateral occipital (in left ventral and lateral views).

cortical regions involved in lifetime alcohol use. Hangover symptoms were also strongly correlated with lifetime and current alcohol use. It is possible we found overlapping/adjacent patterns because hangover symptoms are likely related to both long-term, predisposing factors as well as recent drinking factors (e.g., Robertson et al., 2012; Slutske et al., 2003).

Specifically, past year hangover symptoms were associated with cortical hypogyria of the same right orbitofrontal and left lateral occipital regions that were associated with hypogyria for lifetime alcohol use. Additionally, past year hangover symptoms were uniquely associated with cortical hypogyria of the right parahippocampal gyrus, left temporal pole/parahippocampal gyrus, and right anterior insula. These results are consistent with longitudinal studies in young adults that have found volumetric declines of the bilateral parahippocampal gyri associated with increased alcohol consumption (Meda et al., 2017, 2018). In previous cross-sectional and longitudinal studies, decreased cortical volume of the right insula has also been found to be strongly associated with heavy alcohol consumption in young adulthood (e.g., Heikkinen et al., 2017; Meda et al., 2017). Hence, cortical gyrification associations with past year hangover symptoms could reflect aberrant neural connectivity and activation of alcohol-related processes in young adults.

A limitation of the current study is that it is cross-sectional and does not support directional interpretations. Another limitation is that the current study did not include a control group of nondrinkers/light drinkers. Future research should examine alcohol consumption longitudinally in both nondrinking and drinking young adults to determine if cortical gyrification abnormalities are a consequence or a precipitant of alcohol use. Additionally, there is an issue of co-occurring substance use and comorbidity. In the current study, we attempted to assess for smoking, substance use, and psychiatric diagnoses; however, a limitation here is the amount of missing data for these variables. As such, future research should further examine if these associations with cortical gyrification are specific to alcohol or related more generally to other substance use disorders and psychopathology. Furthermore, although cortical gyrification abnormalities have been proposed to be a marker of neural connectivity abnormalities (Dauvermann et al., 2012; White and Hilgetag, 2011), the current study did not include direct functional MRI measures of alcohol-related processes, such as reward processing and cue-reactivity. Thus, future studies should examine the relationship between alcohol use with both structural and functional measures.

A strength of the current study was the focus on alcohol consumption in young adulthood. Multiple studies have found that heavy alcohol consumption in young adulthood is associated with neurodevelopmental changes that negatively affect cognition (Squeglia et al., 2014b). As such, future research should examine whether cortical gyrification abnormalities are associated with cognition and functioning deficits in young adulthood. Further, the current study found that the most widespread cortical gyrification was associated with increased hangover symptoms. Future research should continue to examine how hangovers and other high-risk drinking behaviors (e.g., binge drinking) are associated with cortical gyrification. Specifically, as previous studies have implicated inflammatory processes in the pathophysiology of alcohol hangovers, research should examine whether neuroinflammation mediates the relationship between hangovers and cortical gyrification.

5. Conclusions

Overall, for the first time, the current study found novel evidence that cortical gyrification is associated with alcohol use in young adulthood. We also found novel evidence that hangover symptoms are associated with widespread hypogyria in regions that overlapped with ahypogyria associated with lifetime alcohol use. Especially interesting was that these patterns of hypogyria occurred in regions involved in reward processing and cue-reactivity. Further, this study provides additional evidence that life events occurring in young adulthood are related to cortical gyrification.

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Contributors

JGK, TMP, and KJS were responsible for the study concept and design. JGK contributed to the acquisition of data. YEM, CLB, CJT, and AMM were responsible for scoring the alcohol use variables. JPYH processed the cortical gyrification data and performed the analyses. JPYH and JGK drafted the manuscript. All authors critically reviewed the manuscript and approved the final version for publication.

Declaration of Competing Interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.drugalcdep.2020.107925.

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