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Effects of low-level alcohol use on cognitive interference: An fMRI study in young adults

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ABSTRACT

Alcohol consumption is widely known to adversely affect human health. Its neuropathology is largely evident in the cerebellum and frontal lobes, particularly in the immature brains of adolescents and young adults. It may also have a long-lasting impact on executive functioning. The Ottawa Prenatal Prospective Study (OPPS) has followed participants over 20 years, from birth to young adulthood, and has collected data on potentially confounding lifestyle variables, such as prenatal drug exposure and current drug use. The present study investigated the neural activity of 29 young adults from the OPPS using fMRI. The main objective was to discover the impact of regular low-level alcohol consumption on the cognitive interference of these participants, as they performed a Counting Stroop task. Results indicated that, despite a lack of performance differences, young adults who use alcohol on a regular basis differ significantly from non-users with respect to their neural activity as they perform this task. Areas that were significantly more activated in users compared to non-users included the cerebellum, thalamus, fusiform gyrus, prefrontal cortex, and precuneus. The observed activity suggests a significant impact of early alcohol use on neurocognitive functioning despite relatively low levels of alcohol consumption.

Introduction

Despite the fact that alcohol consumption is widely known to adversely affect human health, research is only beginning to unveil its ability to disrupt developmental and functional processes in the brain (World Health Organization, 2007). Indeed, individuals diagnosed with alcoholism show significant decreases in gray and white matter volumes and increases in sulcal and ventricular volumes (Pfefferbaum et al., 1992). Both effects worsen for heavy drinkers with age when drinking continues and there is also significant and continued axonal and neuronal injury over time (Harper, 2009; Pfefferbaum, Sullivan, Mathalon, & Lim, 1997; Pfefferbaum et al., 1995). This neuropathology of alcoholism is particularly evident in the frontal lobes, which are especially vulnerable to damage in immature brains of adolescents and young adults (Faden & Goldman, 2005; Meyerhoff et al., 2005). These structural and cellular changes are in line with the evidence accumulated demonstrating that prolonged use of alcohol has a significant negative impact on adult brain function, predominantly with respect to executive functioning (for a review, see Moselhy, Georgiou, & Kahn, 2001).

It is also now well documented that the deleterious impact of alcohol differs among adolescents and adults, with the developing brain of adolescents being more vulnerable to the harmful effects of alcohol (Guerri & Pascual, 2010; Squeglia et al., 2012). However, there appears to be a marked skew in the focus of this initial research, which has predominantly examined the effects of chronic heavy alcohol use and high level drinking (De Bellis et al., 2005; Schweinsburg, McQueeny, Nagel, Eyler, & Tapert, 2010; Schweinsburg et al., 2005; Squeglia et al., 2012; Tapert, Brown, Baratta, & Brown, 2004; Tapert et al., 2001; Wetherill, Squeglia, Yang, & Tapert, 2013). Little attention has been paid to the functional consequences of light to moderate drinking behaviors despite evidence that structural damage accumulates along a dosage continuum (Paul et al., 2008). Further research on the effects of alcohol on the developing brain as well as a consensus on how to

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categorize the levels and patterns of alcohol consumption among adolescents would assist in understanding these functional consequences in the future.

Since its inception, the Stroop task (Stroop, 1935) has proven to be a reliable and valid measure of executive function, and is considered to be a criterion measure of selective attention (Lezak, Howieson, & Loring, 2004; Mead et al., 2002). As a measure of executive functioning, it has been used to discriminate patients with frontal lobe dysfunction from controls (Demakis, 2004; Perret, 1974), and has also been used to demonstrate the extent of neural maturation across developmental stages (Adleman et al., 2002; Marsh et al., 2006). Functional magnetic resonance imaging (fMRI) has been used to identify regions of the brain involved in the Stroop effect. These regions include the cingulate gyrus, prefrontal cortex, and parietal regions, though activity in these areas differs slightly with different task variations (Banich et al., 2000a, 2000b; Milham, Banich, & Barad, 2003; Peterson et al., 2002).

Silveri and colleagues (Silveri, Rogowska, McCaffrey, & Yurgelun-Todd, 2011) used fMRI to examine performance on a Stroop Interference task in adolescents at high risk for alcohol abuse, based on a familial history of alcohol dependence. Compared to low-risk individuals, high-risk individuals showed greater recruitment of a network of frontal lobe regions during performance on this task of inhibition. This greater recruitment of frontal brain regions in high-risk individuals is consistent with previous research suggesting the brain will attempt to maintain performance on cognitively demanding tasks by increasing activation in the compromised and adjacent brain regions (Chang, Yakupov, Nakama, Stokes, & Ernst, 2008; Drummond, Meloy, Yanagi, Orff, & Brown, 2005). Moreover, these results reflect the view in the current literature that neural vulnerabilities exist in at-risk individuals even prior to the initiation of substance use (Everitt et al., 2008; Wetherill et al., 2013).

Banich et al. (2007) used fMRI to compare adolescents with severe substance and conduct problems to controls on the color-word Stroop task. Results indicated clear group differences with respect to brain activity, with patients demonstrating increased activity, compared to controls, in the left hemisphere, including the superior frontal gyrus, middle and superior temporal gyri, caudate, and thalamus, and bilaterally in the parahippocampal gyrus. Another fMRI study by Tapert et al. (2004) examined differences in brain activity in alcohol-dependent young women versus light social drinkers in response to alcohol stimuli in a Stroop-like task. Compared to controls, alcohol-dependent women had increased neural activity in the left anterior cingulate, the left dorsolateral prefrontal cortex (DLPFC), the left inferior frontal gyrus, and bilateral uncus, insula, and precuneus. Although pertinent, results from both of these fMRI studies are confounded by the sample population. For example, the Banich et al. (2007) patients were all male and were in treatment programs for both substance abuse (of potentially more than just alcohol) and conduct disorder. Similarly, Tapert et al. (2004) used only females with heavy substance abuse.

A variant of the original Stroop task, the Counting Stroop, has been developed for use in fMRI studies to minimize unfavorable head movements in the scanner that often occur with verbal responses (Bush et al., 1998). The primary difference in the task is that participants respond using button response pads, and report the number of words in a group of stimulus words. Using healthy controls, neural activity during the Counting Stroop was shown to be consistent with prior research using the original Stroop, demonstrating activity in the anterior cingulate, middle frontal gyrus, left precentral gyrus, left premotor cortex, inferior temporal gyrus, and superior parietal lobule.

Given that alcohol use is frequently accompanied by drug use (legal or illicit), especially in adolescents and young adults (WHO, 2007), it is of particular importance to control for such confounds when assessing performance and brain activity during a task like the Counting Stroop. In light of this, the present paper examines data from the Ottawa Prenatal Prospective Study (OPPS), a longitudinal project that has followed participants over 20 years, from birth, and has collected data on potentially confounding lifestyle and drug exposure variables. This unique cohort permits the examination of the neurobehavioral effects on executive functioning resulting from alcohol use, while controlling for adolescent/young adult drug use and prenatal drug exposure confounds, as well as other lifestyle variables, such as socioeconomic status.

At present, there has been little fMRI research on the resulting impact of alcohol on cognitive development and functioning in young adults, and even fewer studies have controlled for other drugs of use and abuse. In the present study, fMRI was used to examine the effects of low-level alcohol use on executive functioning, particularly selective attention and cognitive interference, in a sample of OPPS participants. It was anticipated that there would be no performance differences between young adult alcohol users and non-users while completing the Counting Stroop. Given the areas activated during the Counting Stroop in healthy controls and the development of the PFC at the critical time of neurodevelopment when regular alcohol consumption started, it was hypothesized that areas of the brain related to executive functioning would be negatively impacted by regular alcohol consumption while performing the Counting Stroop. In particular, we anticipated increased neural activity in young adult alcohol users compared with non-users within the anterior cingulate, parietal, and prefrontal cortices, although these results would likely be less extreme than those observed in chronic heavy drinkers.

Materials and methods

Participants

Fifty participants from the OPPS were randomly contacted until a sample of 35 available and suitable youth was recruited. These 35 participants provided informed consent and were imaged, regardless of sex or drug exposures. Inclusion criteria required that participants were at least 18 years of age, were right-handed, had English as their first language, and had completed a recent comprehensive neuropsychological test battery. All participants met fMRI compatibility criteria, including no metal implants, no pacemaker, no recent surgery, suitable vision for viewing stimuli, and no previous metal in eyes. Participants were excluded if they tested positive for cocaine, opiates, or amphetamines in their urine, or self-reported regular use of any of these drugs (defined as once/month or more; 4 participants). Participants were also excluded if they had a history of an Axis I diagnosis based on the DSM-IV-TR (1 participant), or if any structural abnormalities were detected in their MRI scan (1 participant). No participants included in the current study met diagnostic criteria for conduct disorder.

These criteria resulted in data from 17 alcohol users (9 male, 8 female, mean age of 20, range 19–21 years) and 11 non-users (5 male, 6 female, mean age of 20, range 19–21 years) being included for analyses. Alcohol use was reported as the number of alcoholic drinks consumed per week. Users reported consuming an average of 4.72 drinks/week (SE = 0.74) over 1 to 2 times/week, with first alcohol exposure ranging from age 12–16 for this group (mean age of 14.3). The non-users reported only sporadic use, if any (3 did not drink alcohol at all while the other 9 averaged fewer than 4 drinks/month), with a first exposure to alcohol ranging from 13 to 19 years old (mean age of 15.5).