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A history of adolescent binge drinking in humans is associated with impaired self-movement cue processing on manipulatory scale navigation tasks

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HIGHLIGHTS

- A history of adolescent binge drinking was associated with performance deficits on spatial tasks.
- Binge drinking impaired self-movement cue processing and spared use of environmental cues.
- Performance deficits were not mediated by motor coordination or motivational factors.
- These results further describe the behavioral impairments associated with adolescent binge drinking.

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ABSTRACT

A binge drinking pattern of alcohol consumption has been shown to have an impact on brain structures that continue to develop into late adolescence. These same brain structures have been implicated in processing self-movement cues. The current study applies an array of existing and novel kinematic analysis techniques to characterize performance on manipulatory scale tasks to assess spatial orientation deficits associated with a history of adolescent binge drinking. Using kinematic analysis techniques, a history of adolescent binge drinking in university students was associated with disruptions in outward segment movement organization and less accurate direction and distance estimation in a dead reckoning task. Similar disruptions in performance were found in the bead maze task in the first training block; however, no group differences were observed on subsequent blocks of place training. This is the first study to demonstrate a relationship between adolescent binge drinking in humans and impaired processing of self-movement cues. This pattern of results demonstrates the potential of manipulatory-scale spatial tasks to detect differences in information processing associated with factors known to disrupt normal central nervous system development.

1. Introduction

Animals use multiple sources of information to maintain spatial orientation [17]. One source of information originates from environmental cues (i.e., visual, auditory, olfactory), and animals can learn to use these cues or relationships between them to guide movement. Although researchers have traditionally focused on environmental cue use, self-movement cues (i.e., vestibular, proprioception, optic flow) offer another source of information that is generated as the animal moves through an environment. These self-movement cues can be used for dead reckoning (also referred to as path integration). Dead reckoning is an online navigational strategy that involves processing internally generated self-movement cues while moving through an environment to estimate direction and distance to the point movement originated. [4,13,15,17,36,40,44,53]. Dead reckoning tasks have been adapted for multiple species [33,35,42] and across different scales of human movement [21,26,28,54]. Specifically, human participants have been shown to use dead reckoning-based navigation at virtual [20,60], manipulatory [21,54], and ambulatory [26,39,52] scales. Each scale of movement provides access to different sources of self-movement cues. For example, during ambulatory dead reckoning tasks participants are provided access vestibular, proprioceptive, and motor efferent copies. In contrast, manipulatory scale dead reckoning scale tasks restrict participants to proprioceptive and motor efferent copies sources of self-movement

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cues, whereas participants are restricted to optic flow in virtual reality tasks. Integration of this multi-sensory information depends on the activity of a network of brain structures.

Recent work has provided evidence of a role for the hippocampus, entorhinal cortex, and medial prefrontal cortex in self-movement cue processing. For example, hippocampal damage in humans ([39]; however, see [45]) and rats ([23,27,30]; however see [2]) has been shown to disrupt performance on dead reckoning tasks. This relationship has been supported by functional magnetic resonance imaging work demonstrating hippocampal and prefrontal cortex activation while participants engaged in a virtual dead reckoning task with increased hippocampal activation being associated with the more accurate direction estimation [60]. In addition, similar impairments in self-movement cue processing have been observed in rats subsequent to damage focused on the entorhinal cortex [38,56]. Finally, increased medial prefrontal activation has been observed while human participants engaged in a virtual dead reckoning task [60]. Changes in the function of this network of brain structures may contribute to the age related decline of accuracy observed on dead reckoning tasks [20,28]. Therefore, it is possible to use dead reckoning tasks to investigate other developmental experiences that may influence the function of this network of structures.

Recent work has demonstrated an association between adolescent (12 to 25 years) binge drinking pattern of alcohol consumption (4 to 5 standard alcohol drinks in a 2 h period at least once a month [37]) in humans and deficits in central nervous system function [11,41]. Animal models have complemented this research by demonstrating adolescent binge drinking produces structural changes in structural changes in hippocampus, entorhinal cortex, and medial prefrontal cortex [7,8,12,50]. In addition, adolescence is a developmental period marked by decreased sensitivity to the sedative effect of alcohol [25] and increased sensitivity to the neurotoxic effects of alcohol [12]. These observations are especially troubling considering that the prevalence of binge drinking has been shown to progressively increase throughout adolescence culminating in >40% of university students in the US reporting a history of this pattern of alcohol consumption [55]. This trend has prompted researchers to investigate whether cognitive deficits are associated with this pattern of alcohol consumption during adolescence. Recent work has not shown a relationship between binge drinking and performance on analogous place-learning tasks in humans [46] or rodents [8]; however, this lack of deficit may reflect the inability of traditional place-learning tasks to dissociate between environmental and self-movement cue processing. As of yet, no studies have investigated self-movement cue processing deficits associated with a history of adolescent binge drinking.

The current study uses three human manipulatory-scale tasks to assess spatial orientation in adolescent participants reporting or not reporting a history of binge drinking in the previous six months. Rodent analogues of these tasks have previously been shown to dissociate impaired processing of self-movement cues (dead reckoning task) from spared use of environmental cues (place learning and matching-to-place) associated with damage to the hippocampal formation [23]. The dead reckoning task is a manipulatory scale analogue [54] of the rodent food-hoarding task conducted under dark conditions [27]. Blindfolded participants use their index finger to search the surface of a table for a small piece of Velcro tape. Upon finding the tape, they are instructed to return to the start location. The accuracy in estimating direction and distance to the start location assesses self-movement cue processing in participants. The bead maze-place task is a manipulatory scale analogue of the water maze place-learning task [22]. Participants use their index finger to search for a piece of Velcro tape attached to the bottom of a shallow well of beads. Although the start position varies across trials, the position of the Velcro tape remains fixed. The progressive improvement in estimating direction and distance to the Velcro tape assesses a participant's use of environmental cues, self-movement cues, or a combination of both to encode the direction and distance to a fixed goal position. The bead maze-matching-to-place task is a manipulatory scale analogue of the matching-to-place task in the water maze [22]. Participants are given two trials to find the Velcro tape after it has moved to a new position. The improved performance observed between trials characterizes a participant's ability to update the encoded position of the goal. This collection of manipulatory scale tasks combined with kinematic analysis provides a novel approach to examine the spatial information processing deficits associated with adolescent binge drinking.

2. Methods

2.1. Participants

Northern Illinois University undergraduate students were provided supplemental course credit for their participation in the study. Responses to the Alcohol Use Disorder Identification Test (AUDIT)[3] administered during mass testing at the start of the semester were used to screen for potential Binge Drinkers (BD) and Non-Binge Drinkers (NB). BD participants were contacted if they responded between 6 and 9 on the measures of hazardous alcohol use domain and between 0 and 3 on both dependence symptoms and harmful alcohol domains. NB participants were contacted if they reported responses between 0 and 2 on all three domains. Based on the above criteria, a total of 26 participants were contacted and were run through the tasks. Participants were excluded from the study if they reported a history of traumatic brain injury ($n = 5$), neurological disorder ($n = 1$), or if they failed to follow the instructions ($n = 4$). The resulting sample of NB (3 female, 4 male) participants were an average age of 19.6 (SEM: 0.68) years old and had an average MMSE-2 score of 28.1 (SEM: 0.46). The resulting sample of BD (5 female, 4 male) participants were an average age of 18.9 (SEM: 0.35) years old and had an average MMSE-2 score of 29.4 (SEM: 0.18). All participants self-identified as being right handed. Consistent with previous work ([32]; for a review, see [31]), prevalence of tobacco smoking was higher in the BD (5 of 9) than the NB group (1 of 7).

2.2. Apparatus

2.2.1. Dead reckoning task

Participants were seated in an adjustable chair, such that their forearms rested comfortably on the surface of a rectangular table (0.61 m × 0.91 m). A bullet security camera was positioned perpendicular and above the participant, such that the entire table surface was within the view of the camera (see Fig. 1a). The camera was connected to a DVD recorder. A small piece of Velcro tape (2.5 cm × 2.5 cm) was attached to the surface of the table. The location of the Velcro tape varied across trials. Both a sleeping mask and a black silk scarf were used to blindfold the participants.

2.2.2. Bead maze

The same chair, table, and camera set up was used for the bead maze. The bead maze was a shallow circular well (48.3 cm in diameter and 2.5 cm deep) cut into two sheets of foam board with a third sheet of foam board serving as the base. The well was filled with small (~3 mm diameter) plastic beads, such that the piece of Velcro attached to the base of the well was not visible to the participant.

2.3. Procedure

All procedures were approved by the Northern Illinois University Institutional Review Board. Upon entering the lab, participants provided written consent prior to experiencing any tasks. Next, participants completed the MMSE-2 (PAR, Inc. Lutz, FL, USA), and general medical history was collected. Next, participants were taken into the testing room and instructed to adjust the seat such that their arms were resting