Binge Drinking Reveals Condition-Dependent Trait Expression in Humans: Ethyl Alcohol
Exposure Disrupts Men's Visuospatial Abilities and Women's Social-Cognitive Abilities

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Abstract

This study tested the hypothesis that men's visuospatial abilities and women's social-cognitive abilities are condition-dependent traits that are vulnerable to stressor exposure, binge drinking in this case. Among light drinkers, men's typical advantage on visuospatial tasks ($Ns = 73, 116$; $ds = 0.72, 0.49$) and women's typical advantage on a social-cognitive task ($N = 210$; $d = 0.29$) was confirmed. Among binge drinkers, men's advantage was reduced for one visuospatial task and eliminated for another ($Ns = 102, 93$; $ds = 0.43, -0.26$), and women's advantage on the social-cognitive task was eliminated ($N = 209$; $d = 0.17$). Males who frequently engaged in extreme binges (> 11 drinks/episode) had exaggerated deficits on one of the visuospatial tasks, as did their female counterparts on the social-cognitive task. The results suggest sex-specific vulnerabilities associated with binge drinking, and support an evolutionary approach to the study of these vulnerabilities.

Keywords: sex differences, sexual selection, alcohol, binge drinking, cognitive deficits,

Human sex differences in various cognitive domains are now well established, but their origin is vigorously debated (Archer, 2019; Hyde, 2005; Wood and Eagly, 2002). The finding that the magnitude of many of these sex differences varies across contexts has been interpreted as evidence for environmental and not biological origins (Asperholm, Nagar, Dekhtyar, & Herlitz, 2019). However, an evolutionary perspective can be used to predict and understand these contextual influences while placing them in the same unifying framework used to study sex differences in non-human species, that is, sexual selection (Andersson, 1994; Darwin, 1871). Sexual selection involves competition for mates or other reproductively important resources and discriminative mate choice, all of which result in the exaggeration of the associated traits and an evolutionary emergence of sex differences in those traits.

Critically, these traits are condition dependent—their development and expression is a reliable indicator of the individuals' exposure and resilience to ecological and social stressors (Cotton, Fowler, & Pomiankowski, 2004; Johnstone, 1995; Zahavi, 1975). One result is that any associated sex differences are largest in well-nourished populations that are buffered from exposure to disease and social stressors, as illustrated in the top distributions in Figure 1. As conditions deteriorate, many members of the advantaged sex can no longer build and maintain exaggerated traits and thus the magnitude of any associated sex differences becomes smaller, as illustrated in the bottom distributions in Figure 1. These same traits also appear to be more sensitive to man-made toxins than are other traits (Bortolotti, Fernie, & Smits, 2003; Jašarević et al., 2011) Geary, 2015, 2019). Nearly all of the prior research on condition-dependent trait expression has been conducted with non-human species. We expand this work to our own species and test the key prediction that sex differences found in healthy populations will be smaller in populations that have been exposed to a potential neurotoxin, operationalized here as

64 ethyl alcohol exposure through heavy episodic binge drinking (e.g., Hindmarch, Kerr, &
65 Sherwood, 1991).

66
67 **Figure 1.** Sex differences are largest in healthy populations (top distributions) and become
68 smaller with exposure to stressors (bottom distributions).

69 **Condition-Dependent Traits in Humans**

70 Sex differences in physical size, strength, rate of development, and lifespan are consistent
71 indicators of an evolutionary history of sexual selection in mammals (e.g., Clutton-Brock &
72 Isvaran, 2007). These same sex differences are found in humans and consistent with an
73 evolutionary history of male-male competition in our species (Leigh, 1995; Tanner, 1990).
74 Although the research in this area has not been framed in terms of condition dependence, one
75 supporting example is that men's advantage in height is largest in healthy populations with
76 access to modern health care and becomes smaller in populations exposed to chronic stressors
77 (Perkins, Subramanian, Davey Smith, & Özaltin, 2016). In addition to physical contests,
78 competition among men involves larger travel ranges and use of projectile weapons in traditional
79 contexts, both of which are supported by different aspects of visuospatial ability (e.g.,

MacDonald & Hewlett, 1999). In these contexts, men with larger ranges perform better than other men on standard visuospatial tasks, and also have more wives and children (Vashro & Cashdan, 2015). The same male advantage on visuospatial measures is found in developed nations (Voyer, Voyer, & Bryden, 1995).

As with other primates, competition among women over valuable resources is common (Smuts, 1987; Stockley & Campbell, 2013). The ethnographic record and studies in developed nations indicate that this competition is more likely to manifest as relational rather than physical aggression (Card, Stucky, Sawalani, & Little, 2008; Jankowiak, Sudakov, & Wilreker, 2005). Relational aggression involves of the use of social competencies to undermine the relationships—including those with potential mates—of competitors. In traditional contexts, socially dominant women often have healthier and more surviving children than do submissive ones (e.g., Ji et al., 2013). Women's competitiveness appears to be enhanced by various social-cognitive abilities, including sensitivity to nonverbal cues and facial expressions, especially the facial expressions of other women, that in turn contribute to their advantage in theory of mind, that is, making inferences about the thoughts and feelings of others (Geary, Winegard, & Winegard, 2014). Women's advantages in these and related areas are well documented (e.g., Hall, 1984; Thompson & Voyer, 2014). One potential exception is a heightened sensitivity of men to the angry expressions of other men, as this is a common social-signal in dominance-related conflicts among men (Rotter & Rotter, 1988).

Current Study

The study provides a unique *a priori* test of the hypothesis that men's advantage in visuospatial abilities and women's advantage in social-cognitive abilities will show the same pattern of condition-dependent expression found for sexually selected traits in nonhuman species

(Cotton et al., 2004; Johnstone, 1995; Zahavi, 1975). We used two standard measures of visuospatial abilities, and developed a facial-expression decoding task as a measure of social-cognitive ability, to test this hypothesis as related to recent binge drinking. We expected advantages for men on the visuospatial tasks and an advantage for women on the social-cognitive task among emerging adults who do not drink alcohol or are light drinkers, and attenuated sex differences among binge drinkers. To control for potential group differences in overall cognitive ability, we administered a vocabulary test that does not typically show sex differences and is a reliable measure of general intelligence (Jensen, 1998).

Method

Participants

Participants were 680 undergraduates—295 men (Age: $M = 19.3$, $SD = 1.42$) and 385 women (Age: $M = 18.8$, $SD = 0.92$)—recruited from Introductory Psychology courses at a large, public, Midwestern University between 2016 and 2019. Two-hundred and sixty-one participants were excluded for the following reasons: (1) because they did not answer questions about binge drinking (because their battery of questionnaires did not include the binge drinking items described below, $N = 160$), or because they chose not to respond, $N = 91$; (2) because they did not complete the vocabulary test ($N = 8$); or (3) because they failed to follow experiment instructions ($N = 2$). Of the remaining 419 participants (233 women), those who completed one ($N = 175$; 84 women) or another ($N = 209$; 125 women) visuospatial task were included in the analyses, with the exception of 35 individuals whose performance on the first visuospatial task was below chance. All 419 participants contributed data to analyses of the social-cognitive task.

An *a priori* power analysis was performed assuming medium (partial $\eta^2 = .06$; Cohen's $f = 0.25$) interaction effects. Medium interaction effects were assumed because this was the first *a*

priori study of its kind, and so a background literature including expected interaction effect sizes was not available. To achieve 80% power using a four-group contrast, a sample size of 45 per group, or 180 total was suggested. We biased participant recruitment to meet and exceed this sample size suggestion to ensure an adequately powered sample. The first 210 participants were recruited from the pool of students regardless of binge drinking status reported during a mass pretesting session. The next 209 participants were recruited in batches, targeting both light- and heavy-binge drinkers according to responses collected during mass pretesting.

Measures

Vocabulary Test. The Vocabulary Test II was included as a measure of general intelligence and used as a control variable (Ekstrom, French, & Harman, 1976). The test includes 36 vocabulary words and requires participants to choose the synonym of a target word from among five options (e.g., target vocabulary word ‘edifice’, with synonym options of ‘small insect’, ‘heir’, ‘front’, ‘large building’, and ‘learning’). The score is the number of correct synonyms selected ($M = 21.10$, $SD = 3.91$, $\alpha = .79$).

Binge Drinking. We assessed binge drinking using a battery of questionnaires compiled by the Multi-disciplinary Alcoholism Research Center (MARC) at the University of Missouri, which have been used in numerous previous studies (e.g., Martins, Bartholow, Cooper, Von Gunten, & Wood, 2018). Frequency of binge-drinking in the past month was measured using three items: (1) a regular binge, “*In the past 30 days, how many times have you had five or more drinks in a single sitting?*”; (2) an extreme binge, “*In the past 30 days, how many times have you had twelve or more drinks at a single sitting?*”; and (3) a binge with a more stringent time-frame likely to quickly produce a high Blood Alcohol Concentration, “*During the last 30 days, how often did you have 5 or more (males) or 4 or more (females) drinks containing any kind of*

149 *alcohol in within a two-hour period?”* Responses were made using an eight-point scale ranging
150 from 0 (“*Did not have ____ or more drinks in ____*,”) to 8 (“*twice a day or more*”). All items were
151 recoded to a frequency per week scale. Binge drinking items were positively correlated ($r_s = .50$
152 to $.80$, $p_s < .001$) and aggregated to create a composite binge drinking variable ($\alpha = .89$), in line
153 with prior work (e.g., Martins et al., 2018).

154 Predictions from Geary (2015) specify that sex differences should be present in groups of
155 people exposed to few stressors, whereas diminished sex differences should be apparent in
156 groups of people exposed to more stressors. The distribution of scores on the binge drinking
157 composite variable was heavily positively skewed (see <https://osf.io/r7b5x>), with roughly half of
158 the respondents reporting little-to-no binge drinking and the other half of the respondents
159 distributed in a long “tail” with varying levels of binge drinking. Thus, from the composite binge
160 drinking score we created two groups of participants: a low binge drinking group ($N = 210$; $M =$
161 0.09 , $SD = 0.19$) and a high binge drinking group ($N = 209$; $M = 2.93$, $SD = 2.51$). These groups
162 were formed on the basis of a split dictated from the ranges of the drinking scores (see the *Hmisc*
163 package in R). Data from the low binge drinking group were used to confirm whether the
164 visuospatial and social-cognitive measures were capturing the expected sex differences, whereas
165 data from the high binge drinking group permitted tests of the prediction that the magnitude of
166 these sex differences will be smaller following stressor exposure.

167 **Visuospatial Ability.** The Mental Rotation Test (MRT) involves the three-dimensional
168 mental rotation of 24 geometric figures presented on a computer monitor (Peters et al., 1995). In
169 each trial, a target geometric figure is presented along with four response options depicting
170 figures rotated to various degrees. Participants are required to identify the two out of four
171 response options that correctly depict the target figure. The trial ends when participants indicate

their second response by pressing a corresponding button, and the next trial begins immediately thereafter. Scoring on each trial was based on whether participants correctly identified both rotations of the target figure. Reliability estimates based on response accuracy ($M = 0.60$, $SD = 0.23$, $\alpha = .92$) and response time ($M = 25889.1$ ms, $SD = 8136.16$, $\alpha = .95$) were excellent.

The MRT was administered via computer. Typically, this task is administered via pencil and paper and participants work at their own pace. To ensure that our modifications were not affecting performance, we assessed its psychometric properties and whether it was capturing the expected sex difference among the first 175 participants. Analyses of MRT performance confirmed the expected male advantage, but a relatively large number of participants ($N = 35$) exhibited chance levels of performance. We therefore replaced the task with a less difficult one, the Judgment of Line Angle and Position Test (JLAP; Collaer & Nelson, 2002).

The JLAP Test involves comparing the angle of a single target line to the angles of 15 comparison line options presented in an array, as shown in Figure 2 (Collaer & Nelson, 2002). In each of 20 trials, a target line is randomly selected from the 15 line options, and participants must identify which of the options matches the angle of the target line. The trial ends when the participant indicates using the computer mouse which of the 15 lines matches the target line, after which the next trial begins. Accuracy precision (distance between the response option and the target line) and response times are recorded from each trial. Better performance is indicated by a smaller difference between the angle of the chosen option and that of the target line (i.e., less negative value). Precision reliability was modest ($M = -0.33$, $SD = 0.35$, $\alpha = .57$), but response time reliability was excellent ($M = 3848.51$, $SD = 650.54$, $\alpha = .87$).

Figure 2. Example item from the Judgment of Line Angle and Position (JLAP) Test.

Social-Cognitive Ability. The Facial-Expression Decoding Task (Hone, Scofield, Bartholow, & Geary, *in press*), which assesses the speed and accuracy of emotion recognition, was used as a measure of social-cognitive ability. The task involves identifying the emotion being expressed in each of 34 faces, which begin as highly pixelated objects and then slowly come into focus. The images were selected from freely available face image databases (see Hone et al., *in press*). Each face is presented within a movie file comprising 78 frames that range from completely obscured to completely clear with regard to pixelated noise. Frames are separated by a 600 ms delay, yielding stimulus “movies” that are approximately 45 sec long. The 34 stimulus movie files (17 male; 17 female) each portray faces displaying one of seven emotions (happy, angry, surprise, fear, sad, disgust, neutral). Participants’ task on each trial is to press a key once they recognize the emotion being displayed on the face, which halts the movie and replaces the face image with a visual mask (500 ms duration). Following the mask, a screen listing the seven emotion response options is displayed and the participant chooses the displayed emotion using the keyboard number pad (numbers 1-7).

The next trial begins immediately after the participant responds. Across the task, each of the seven emotions is presented at least four times, with at least two male faces and at least two female faces displaying each emotion. In this study, a subsample of participants ($N = 230$) were presented with two additional angry male faces. Primary variables include facial-expression decoding accuracy ($M = 0.70$, $SD = 0.09$, $\alpha = .58$) and response time ($M = 2183.79$, $SD = 405.19$, $\alpha = .83$). The facial-expression decoding task was developed expressly for this study. Thus, as with the MRT, we assessed its psychometric properties and whether it was capturing the expected sex difference among the first 175 participants (it was).

Procedure

The study protocol was approved by the University of Missouri Institutional Review Board and carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki. Participants were invited to participate in a 90-minute laboratory session. Upon arrival, a research assistant obtained informed consent and the participant was seated at a computer station. Participants first completed one of the visuospatial tasks and the facial-expression decoding task in a randomized order, after which they completed the vocabulary test and alcohol use measures, in a randomized order. The cognitive tasks were programmed using E-Prime software (Psychology Software Tools, Sharpsburg, PA), and the questionnaire measures were administered using Qualtrics software (<https://www.qualtrics.com>).

Analyses

Trial-level multilevel modeling was used to assess sex and group (binge drinking) differences in visuospatial abilities and facial-expression decoding. The vocabulary score was included as a covariate in all models. Models assessing accuracy additionally controlled for individual variation in response times. Sex by binge drinking group interactions were tested by

specifying interaction contrasts, following guidelines from Rosnow and Rosenthal (1995). This entails testing the group means for the four conditions (low binge drinking men, high binge drinking men, low binge drinking women, and high binge drinking women) against the predicted pattern of means for sex difference attenuations (low binge drinking advantaged sex: +2, high binge drinking advantaged sex: +1, low binge drinking disadvantaged sex: -2, high binge drinking disadvantaged sex: -1), afforded by *a priori* predictions (Geary, 2015). Post-hoc comparisons were used to examine sex differences for each binge drinking group separately. That is, we first confirmed expected sex differences in accuracies or response times for the visuospatial tasks and social-cognitive task in the low binge drinking group. Then, for measures exhibiting sex differences, we predicted and tested for the attenuation, elimination, or reversal of sex differences in the high binge drinking group. Finally, to assess potential dose-response effects we examined the relation between the frequency of two-hour binge episodes and extreme binge episodes and task outcomes within the high binge drinking group, separately for men and women.

All analyses were performed in R, using the *lme4* package. The experiment reported here was not formally pre-registered but the core hypotheses regarding sex-specific vulnerabilities in visuospatial and social-cognitive abilities were developed and reviewed prior to the study (Geary, 2015, Table 5.1, pp. 231-265; Geary, 2019, Figure 7). De-identified data and experimental code can be found online at <https://osf.io/r7b5x>.

Results

Data were first screened for outliers. Seventy-one out of 4,177, and 30 out of 4,230 trials on the MRT and JLAP Test, respectively, were identified as outliers (> 3 SD from the mean of the scaled response time data) and were removed from further analysis. On the facial-expression

decoding task, 372 out of 19,648 response time trials were marked as outliers, and were similarly removed from further analysis. Table 1 includes descriptive statistics for the vocabulary test and cognitive test/task measures.

Table 1. *Descriptive statistics.*

Test/Task	Sex	Vocabulary Test	Response Time	Accuracy/Precision
MRT	Women	21.21(3.96)	26106.10(8079.77)	0.55(0.22)
	Men	20.87(4.07)	25688.79(8227.47)	0.65(0.23)
JLAP Test	Women	21.06(3.73)	3826.38(651.98)	-0.35(0.33)
	Men	20.86(3.99)	3881.44(650.90)	-0.31(0.39)
Facial-Expression	Women	20.99(3.82)	2137.73(391.38)	0.70(0.09)
Decoding Task	Men	21.25(4.03)	2241.48(415.74)	0.70(0.09)

Vocabulary

As noted, vocabulary was used as a covariate to control for the potential influence of intelligence on task performance. Ancillary analyses indicated that low binge drinkers ($M = 21.50$, $SD = 3.83$) had slightly higher vocabulary scores than high binge drinkers ($M = 20.70$, $SD = 3.97$), $F(1,415) = 4.94$, $p = .027$, $d = 0.20$. There were, however, no sex differences in vocabulary scores, $F(1, 415) = 0.46$, $p = .498$, nor was there a significant interaction between sex and binge drinking group, $F(1, 415) = 0.49$, $p = .483$. In the low binge drinking group, men ($M = 21.57$, $SD = 4.28$) and women ($M = 21.46$, $SD = 3.56$) had similar vocabulary scores, $F(1,208) = 0.04$, $p = .838$. Likewise, there was no significant difference between men's ($M = 21.02$, $SD = 3.86$) and women's ($M = 20.36$, $SD = 4.07$) vocabulary scores in the high binge drinking

group, $F(1,207) = 1.44, p = .232$. Thus, any sex differences on the visuospatial and social-cognitive tasks are unlikely to be related to general cognitive ability.

Mental Rotation Test (MRT)

Figure 3 shows mean values for both accuracy and response times for the MRT. The interaction contrast between sex and binge drinking (low binge drinking men: +2, high binge drinking men: +1, low binge drinking women: -2, high binge drinking women: -1) revealed an attenuation effect across binge drinking group, $F(1,163.43) = 12.16, p = .001, r = .27$. Planned comparisons showed that low binge drinking men ($M = 0.68, SD = 0.47$) were more accurate than low binge drinking women ($M = 0.53, SD = 0.50$), $F(1,66.28) = 8.58, p = .005, d = 0.72$. Men were also more accurate than women in the high binge drinking group (Men: $M = 0.62, SD = 0.49$; Women: $M = 0.56, SD = 0.50$), but the magnitude of their advantage was smaller than that observed in the low binge drinking group, $F(1,96.07) = 4.47, p = .037, d = 0.43$. The interaction contrast for response times (low binge drinking men: -2, high binge drinking men: -1, low binge drinking women: +2, high binge drinking women: +1) was not significant, $F(1,169.36) = 0.50, p = .480$.

Figure 3. Mean values for accuracy and response times by sex and binge drinking group for the Mental Rotation Test (MRT).

As predicted, within the high binge drinking group, neither the frequency of binge episodes (> 4 drinks), $r(43) = -.13, p = .389$, nor frequency of extreme binge episodes (> 11 drinks), $r(43) = -.13, p = .381$, was related to women's accuracy on the MRT. The frequency of men's binge episodes was not related to MRT accuracy, $r(55) = .01, p = .957$, but a higher frequency of extreme binge episodes was associated with lower accuracy, $r(55) = -.32, p = .014$.

Judgment of Line Angle and Position (JLAP) Test

Figure 4 shows mean values for both accuracy and response times for the JLAP Test. As indicated previously, better performance is reflected in less negative values. The *a priori* interaction contrast (low binge drinking men: +2, high binge drinking men: +1, low binge drinking women: -2, high binge drinking women: -1) for accuracy precision was not significant, $F(1, 200.52) = 2.50, p = .116$. Inspection of the means suggests that this was because the predicted attenuation of sex differences was even more pronounced than we expected, resulting in a reversal of the advantage typically observed for men. Thus, we conducted a follow-up analysis using contrast weights informed by the observed means (low binge drinking men: +2, high binge drinking men: -1, low binge drinking women: -2, high binge drinking women: +1). This contrast was significant, revealing a sex difference reversal across binge drinking groups, $F(1, 200.52) = 7.82, p = .006, r = .20$.

Planned comparisons in the low binge drinking group revealed that men ($M = -0.24, SD = 0.81$) were more accurate than women ($M = -0.39, SD = 1.43$), $F(1, 112.47) = 6.69, p = .011, d = 0.49$. Men's advantage in accuracy was not evident in the high binge drinking group (Men: $M = -0.35, SD = 1.43$; Women: $M = -0.27, SD = 0.78$), $F(1, 86.96) = 1.45, p = .232, d = -0.26$. The

interaction contrast (low binge drinking men: -2, high binge drinking men: -1, low binge drinking women: +2, high binge drinking women: +1) was not significant for response times, $F(1,202.91) = 1.14, p = .287$.

Figure 4. Mean values for precision (lower scores mean less error) and response times by sex and binge drinking group for the Judgment of Line Angle and Position (JLAP) Test.

Within the high binge drinking group, neither the frequency of binge episodes (> 4 drinks) nor the frequency of extreme binge episodes (> 11 drinks) was related to precision accuracy for either sex, $r_s = .12$ to $.15, p_s > .300$.

Social-Cognitive Ability: Facial-Expression Decoding Task

Figure 5 shows mean values for both accuracy and response times (correct trials) for the facial-expression decoding task. The interaction contrast between sex and group was not significant for accuracy (low binge drinking men: -2, high drinking binge men: -1, low binge drinking women: +2, high binge drinking women: +1), $F(1,408.25) = 0.10, p = .755$, but was significant for response times (low binge drinking men: +2, high binge drinking men: +1, low binge drinking women: -2, high binge drinking women: -1), $F(1,415.72) = 7.22, p = .007, r =$

.15. Planned comparisons in the low binge drinking group indicated women were significantly faster ($M = 1992.02$ ms, $SD = 1150.70$) than men ($M = 2128.33$ ms, $SD = 1252.63$) in correctly decoding facial expressions, $F(1,210.88) = 5.40$, $p = .021$, $d = 0.29$. Women's advantage in speed of decoding facial expressions was not evident in the high binge drinking group (Men: $M = 2130.87$ ms, $SD = 1228.78$; Women: $M = 2087.54$ ms, $SD = 1183.89$), $F(1,203.64) = 0.69$, $p = .406$, $d = 0.17$.

Figure 5. Mean values for both accuracy and response times for the Facial-Expression Decoding Task.

Within the high binge drinking group, the frequency of binge drinking episodes (> 4 drinks) was unrelated to facial-expression decoding response times for women, $r(98) = .16$, $p = .113$, but women who engaged in a greater frequency of extreme binge episodes (> 11 drinks) were slower at detecting emotions, $r(98) = .27$, $p = .008$. For high binge drinking men, neither the frequency of binge episodes, $r(107) = -.09$, $p = .340$, nor the frequency of extreme binge episodes, $r(107) = -.10$, $p = .310$, was related to speed of facial-expression decoding.

As noted in the introduction, if women's advantage in decoding facial expressions is related to female-female relational aggression, they might be particularly good at decoding the expressions of other women. The one potential exception to women's overall advantage might be found in men's of decoding other men's angry facial expressions, a social signal in the context of male-male competition (Geary, 2015). Thus, we conducted follow-up analyses to test these more specific predictions—that binge drinking women will be particularly disadvantaged in the processing of women's facial expressions, and that binge drinking men will show deficits in the recognition of angry male faces. There was no significant participant sex by stimulus sex interaction for accuracy, $F(1, 1093.48) = 0.58, p = .445$. However, among low binge drinkers, the interaction contrast (women/female faces: -2, women/male faces: -1, men/female faces: +2, men/male faces: +1) between participant sex and stimulus sex was significant for response times, $F(1, 842.62) = 7.42, p = .007, r = .11$. This indicated that women were especially fast at responding to the facial expressions of other women. Among the high binge drinking group, this interaction contrast was no longer significant, $F(1, 946.61) = 1.71, p = .191$, indicating that women's advantage in decoding female facial expressions was not evident among binge drinkers. There was no significant sex difference in response times for decoding male angry facial expressions in either the low binge drinking, $F(1, 207.04) = 1.97, p = .162$, or high binge drinking group, $F(1, 211.55) = 0.02, p = .879$. The lack of a sex difference among the low binge drinkers indicates that the stimuli we used were not sensitive enough to test our prediction.

Discussion

A large body of scientific literature has established that men tend to outperform women in visuospatial abilities (e.g., MacDonald & Hewlett, 1999), whereas women tend to outperform men in social-cognitive skills (e.g., Hall, 1984; Thompson & Voyer, 2014). The magnitude of

these sex differences varies across context and an evolutionary perspective can situate these contextual influences in the framework of sexual selection (Darwin, 1871). Sexual selection theory posits that visuospatial (favoring men) and social-cognitive (favoring women) sex differences reflect sexually selected traits that confer advantages in competition for mates or other reproductively important resources and discriminative mate choice under favorable conditions. Following Zahavi (1975) and research on condition dependent trait expression in non-human species (Cotton et al., 2004; Johnstone, 1995), Geary (2015, 2019) proposed that these sex differences are condition dependent in humans, such that their development and expression is a reliable indicator of exposure to, and resistance to degradation by stressors. The current study is the first to directly test this hypothesis in humans, and to propose that recent binge drinking acts as a neurotoxic stressor disrupting sexually selected cognitive abilities in sex-specific ways.

The typical advantages of men in visuospatial abilities (Voyer et al., 1995) and of women in social-cognitive abilities (Hall, 1984; Thompson & Voyer, 2014) were replicated among a group of emerging adults who never or rarely engage in binge drinking. These sex differences were greatly attenuated or even reversed in a group of emerging adults who at least occasionally engage in binge drinking. Given the prevalence of binge drinking in this population—current estimates place the percentage of college student binge-drinkers at 40-50% (Croteau & Morrell, 2019; Krieger, Young, Anthenien, & Neighbors, 2018)—these findings suggest that sex-specific deficits among college students might be widespread. Recent data also indicate that although the prevalence of binge drinking among adolescents has declined in recent years (Chung, 2018), emerging and young adults are engaging in more binge drinking than in the past, reflecting a secular shift in the age of peak binge drinking (Patrick et al., 2019).

These high prevalence rates and increasing age of peak heavy episodic binge drinking are especially concerning in light of the current findings, given that mate competition and choice are most intense during this period. During the years that coincide with elevated binge drinking rates, competition for mating relevant resources peaks and creates a period of high risk and high reward with regard to engaging in mating effort (Hill & Chow, 2002). Indeed, binge drinking may be an attractive risk-taking behavior to emerging adults in part because it serves as a costly social signal with the potential to yield high gain in a competitive mating market (Aung, Hughes, Hone, & Puts, *in press*; Hill & Chow, 2002). Our findings highlight that binge drinking does indeed come with costs, as expected of sexually selected signals (Zahavi, 1975).

Under natural conditions, condition-dependent traits are vulnerable to chronic malnutrition, disease, or social conflict and appear to be more sensitive to man-made toxins than other traits (see Geary, 2015, 2019). Although heavy episodic exposure to ethyl alcohol might not be as detrimental as chronic exposure to natural stressors or many other toxins, chronic, heavy exposure to alcohol can result in short-term and sometimes longer-term but subtle deficits in memory and cognition (e.g., Goudriaan, Grekin, & Sher, 2007). Binge drinking might then reveal sex-specific vulnerabilities in visuospatial and social-cognitive abilities. Some previous studies of alcohol abuse have assessed similar abilities but sex differences are not always reported (Folgueira-Ares et al., 2017). When they are reported, the pattern of sex-specific deficits is mixed (Haut, Beckwith, Petros, & Russell, 1989; Weissenborn & Duka, 2003). These prior studies often have been based on relatively small samples and have used standard neuropsychological measures that might not be sensitive to sex-specific deficits.

From an evolutionary perspective, sex-specific vulnerabilities will generally be more evident for traits with larger sex differences (Geary, 2017). Our results provide preliminary

evidence in support of this hypothesis. Men's advantage on both visuospatial tasks was smaller among binge drinkers than among light drinkers and non-drinkers. Moreover, there was evidence for a dose-response effect for mental rotation, whereby very high and frequent exposures to ethyl alcohol (extreme binges) were related to worse performance, but only among men. At the same time, these same men did not show exaggerated deficits in the speed of identifying emotions displayed in facial expressions. In judging line angles and position, binge drinking women were more accurate than were binge drinking men, a reversal of the standard sex difference in visuospatial abilities and of our findings for non-binge drinkers. We did not, however, find evidence for a dose-response effect for this measure. It is possible that men's performance on this spatial measure is disrupted by more moderate levels of alcohol exposure with no further deficits with added exposures, but this remains to be determined.

In contrast, binge drinking women did not show visuospatial deficits relative to women who did not engage in binge drinking, but they were slower at identifying emotions displayed in facial expressions, especially the expressions of other women. There also was evidence of a dose-response effect in this measure, restricted to women. That is, women who frequently engaged in extreme binges were slower at emotion detection than were other women, but these same extreme binge drinking women did not show exaggerated deficits for mental rotation. This pattern is essentially a mirror image of that observed among men who frequently engaged in extreme binges. The overall pattern of sex-specific deficits is consistent with the expression of condition-dependent traits in other species (Cotton et al., 2004; Johnstone, 1995; Zahavi, 1975), and supports the more general hypothesis that the sex differences in visuospatial and social-cognitive abilities stem from different patterns of intrasexual competition among our male and female ancestors, respectively (Geary, 2015; Geary et al., 2014).

Although this study was designed based on established predictions (Geary, 2015, 2019) that provided for *a priori* hypothesis testing based on well-established patterns in non-human species, the study provides only a quasi-experimental test of those predictions. It is possible that the differences across high- and low-binge drinkers preceded recent drinking episodes, as indicated by modestly lower vocabulary scores for the binge drinkers. If there were broader cognitive differences across the drinking groups, however, then the binge drinkers should have performed more poorly than non-drinkers on all cognitive tasks, independent of sex and not in a sex-specific manner. Moreover, because vocabulary is a good indicator of general intelligence, any binge drinking group differences on the visuospatial and social-cognitive tasks should have disappeared with statistical control of vocabulary scores, but they did not. Although our results are not definitive, they are unique and speak to the utility of using sexual selection as a means to identify and study sex-specific vulnerabilities, not just those associated with binge drinking but with exposure to myriad stressors.

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Author Contributions

D. C. Geary developed the study concept and B. D. Bartholow provided critical input on the study measures. All authors contributed to the study design. E-Prime files were created by L. S. E. Hone and R code was written by J. E. Scofield. Testing and data collection were performed by L. S. E. Hone and J. E. Scofield. L. S. E. Hone performed pilot data analyses and J. E. Scofield performed the final data analysis and interpretation under the supervision of D. C. Geary and B. D. Bartholow. L. S. E. Hone, J. E. Scofield, and D. C. Geary drafted the manuscript, and B. D. Bartholow provided critical revisions. All authors approved the final version of the manuscript for submission.

Competing Interests Statement

The authors declare no conflicts of interest with respect to the authorship or the publication of this article.

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