Addiction

RESEARCH REPORT

doi:10.1111/j.1360-0443.2009.02880.x

The effects of binge drinking on college students' next-day academic test-taking performance and mood state

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ABSTRACT

Aim To assess the effects of binge drinking on students' next-day academic test-taking performance. **Design** A placebo-controlled cross-over design with randomly assigned order of conditions. Participants were randomized to either alcoholic beverage [mean = 0.12 g% breath alcohol concentration (BrAC)] or placebo on the first night and then received the other beverage a week later. The next day, participants were assessed on test-taking, neurocognitive performance and mood state. **Participants** A total of 196 college students (≥21 years) recruited from greater Boston. **Setting** The trial was conducted at the General Clinical Research Center at the Boston Medical Center. **Measurements** The Graduate Record Examinations© (GREs) and a quiz on a lecture presented the previous day measured test-taking performance; the Neurobehavioral Evaluation System (NES3) and the Psychomotor Vigilance Test (PVT) measured neurocognitive performance; and the Profile of Mood States (POMS) measured mood. **Findings** Test-taking performance was not affected on the morning after alcohol administration, but mood state and attention/reaction-time were affected. **Conclusion** Drinking to a level of 0.12 g% BrAC does not affect next-day test-taking performance, but does affect some neurocognitive measures and mood state.

Keywords Academic performance, binge drinking, intoxication, mood state, neurocognitive performance, students.

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Submitted 27 July 2009; initial review completed 30 September 2009; final version accepted 29 October 2009

INTRODUCTION

The National Advisory Council of the National Institute on Alcohol Abuse and Alcoholism (NIAAA) defines binge drinking as attaining a blood alcohol concentration (BAC) of 0.08 g% or more, corresponding, for most adults, to five or more drinks (more than four if female) in about 2 hours [1]. In the United States, both binge drinking and heavy drinking (binge drinking at least five times in the last 30 days [1]) peak at age 21 [2].

Although college students have lower rates of daily drinking than their non-college peers, they have higher rates of binge drinking [3], with 32–44% reporting binge drinking [4]. Not surprisingly, 60–75% of college students experience at least one hangover a year, 27% report one to two hangovers and 34% report 12–51 hangovers [5].

Serious negative consequences associated with student drinking include death [6], injury, suicide, fighting, unprotected sex, rape, property damage, and legal problems; academic difficulties are, however, the most frequently reported consequence of excessive student drinking [7]. Academic problems resulting from heavy drinking can occur through several mechanisms: hangover results in missing morning classes; drinking uses time otherwise spent studying; drinking impedes next-day learning in class or, when studying, by affecting memory retention [8]; and personal and interpersonal problems resulting from heavy drinking may make it difficult to focus on school work [9,10].

A number of surveys have shown relationships between college students' drinking and academic difficulties [7,9–15]. Other survey studies, however, have found that the relationship of drinking and academic performance disappeared after controlling for pre-college differences in academic performance [16,17].

Little experimental work has been published on the effects of student drinking on academic performance. There is, however, a body of experimental research on the effects of intoxication on next-day performance ('residual effects of alcohol'), as measured by neurocognitive laboratory tests or occupational training simulators. Because academic performance is the occupation of students, this research is relevant to the question of whether intoxication in the evening impairs students' next-day test-taking ability, when blood alcohol concentration (BAC) has returned to zero. Several studies found residual alcohol effects on simulated occupational tasks [18–29]. However, in other experimental studies residual effects of intoxication were not found for occupational tasks [30–34]. Some investigators have found residual alcohol effects on various neurocognitive tests [35–44], but other studies found no impairment on tests of manual dexterity or neurocognitive performance [39,45–49].

Inconsistencies among study findings may be the result of factors such as the type of performance measured the amount of alcohol administered, the age and alcohol tolerance of participants and the length of time from drinking to testing [49].

We conducted a randomized cross-over trial to examine the extent to which alcohol intoxication affects college students' next-day academic performance at zero BAC. Neurocognitive tasks relevant to academic performance were also assessed. We hypothesized that drinking to about 0.12 g% BrAC would not affect next-day performance on academic tests requiring long-term memory (e.g. standardized academic achievement tests), but would affect performance on tests of recently learned material and on neurocognitive tests requiring sustained attention and speed. To our knowledge, this is the first study to explore experimentally the relationship between binge drinking and academic performance.

METHODS

Participants

Participants were university students recruited from greater Boston, Massachusetts, who were between 21 and 24 years of age and met the following criteria: (1) no drinking problems (score <5 on the Short Michigan Alcohol Screening Test (SMAST)) [50] and no history of treatment or counseling for chronic alcohol problems; (2) consumption of more than five drinks (more than four if female) on a single occasion at least once in the 30 days prior to screening; (3) no health problems or current medication use contraindicated for alcohol; (4) no diagnosis of sleep disorders or use of sleeping medications; (5) fluent English; (6) recently graduated from, or currently attending, an institution of higher learning; (7) not working night shifts; (8) not a daily smoker; (9) not traveled across two or more time zones in the prior month; and (10) if female, negative pregnancy test and not nursing. Female participants' menstrual cycle phase was documented, but not a factor in scheduling their experimental sessions [51–53]. For safety reasons, regular tobacco users were excluded because participants were not allowed to leave the laboratory to smoke. This exclusion also avoided possible confounding due to nicotine withdrawal during the study sessions. Before beverage administration, participants who reported consuming alcohol, caffeine, prescription or over-the-counter drugs within the prior 24 hours, or who had had a positive breath alcohol test (BrAC), were rescheduled (see Table 1 for participant characteristics).

No information about individuals' participation was provided to institutions attended by volunteers. Participants were paid $300 upon completion of the study, or a pro rata amount if their participation ended prior to completing the study. The Institutional Review Boards at Boston Medical Center and Brown University approved this study.

Study design

We used a placebo-controlled, double-blind, within-subjects, repeated-measures design to study the residual effects of alcohol, with participants serving as their own controls. Participants took part in the study over 4 days: an evening and the next morning, followed a week later by the same schedule. All participants received two beverages (alcohol and placebo) in counterbalanced order (alcohol week 1 versus alcohol week 2).

Study procedures

Recruitment and screening

Participants were recruited by advertisements in local newspapers and websites (e.g. Facebook and Craig's List). Interested individuals were first screened by telephone and then in person, including a physician examination (after informed consent). To reduce potential confounding by sleep pattern variations, participants were instructed to keep a sleep diary, comply with a minimum regimen of 8 hours sleep (retiring to bed no later than midnight and awaking no later than 8 a.m.), with confirmation call-ins to a time-stamped answering machine each evening and morning for the 3 nights prior to

Table 1 Participant characteristics.

Total (n = 193)	
Sex	
Male	107 (55.4%)
Female	86 (44.6%)
Age	
Mean ± SD	21.47 (0.64)
Range	21–24
Race	
White	155 (80.3%)
Black	8 (4.2%)
Asian	13 (6.7%)
Other	17 (8.8%)
Family history of alcohol problems	
Yes	71 (36.8%)
No	119 (61.7%)
Adopted	3 (1.6%)
Mean age of drinking onset	
Mean ± SD	16.18 (1.66)
Range	11–21
Maximum breath alcohol concentration (BrAC)	
Mean ± SD	0.12 (0.01)
Range	0.09–0.16
Amount of alcohol received (ml)	
Male: mean ± SD	1609 (288)
Male: range	1052–2308
Female: mean ± SD	1122 (178)
Female: range	683–1606
% with hangover	
Rated hangover >1 on the morning following alcohol administration when asked to rate their hangover on a scale from 0 (no hangover) to 7 (incapacitating hangover)	69.8%
Morning mean AHS score	
Placebo condition	0.71 (0.35)
Alcohol condition	1.38 (0.81)

AHS: Acute Hangover Scale; SD: standard deviation.

Table 2 Schedule of study procedures.

Orientation/consent 10 a.m.–12 p.m.	Orientation. Consent. Enrollment questionnaires. Medical screening by physician
Evening sessions 4 p.m.–5 p.m.	Dinner, screened for adherence to study protocol. BrAC tested. Pregnancy tests administered to females
5 p.m–6 p.m	Family Tree questionnaire administered. Practice tests to familiarize participants with GRE and PVT
6 p.m–7.30 p.m	Video lecture based on next-day's quiz. Participants study lecture notes for 1 hour
7.30 p.m–8.45 p.m	Practice NES3 test
8.45 p.m–11 p.m	Beverage administration
	Repeated BrAC tests
11 p.m	Lights out
	Observed throughout night by EMT
Morning sessions 7 a.m.–7.30 a.m.	Subjects awakened. Morning questionnaires
7.30 a.m.–8 a.m.	Breakfast
8 a.m.–11 a.m.	BrAC tests
	POMS questionnaire, quiz on video lecture, GRE, NES3, PVT, self-rated performance questionnaire
12.30 p.m.	Subjects dismissed

BrAC: breath alcohol concentration; GRE: Graduate Record Examinations; PVT: Psychomotor Vigilance Test; EMT: emergency medical technician; POMS: Profile of Mood States; NES3: Neurobehavioral Evaluation System.

experimental sessions. Participants were told not to nap and, for 24 hours prior to their experimental sessions, to abstain from alcohol, medications not already approved by the study physician, sleep aids, recreational drugs and caffeine. To familiarize participants with the standard academic achievement tests, they were required to read and complete a practice booklet issued by the testing service.

One week after screening and enrollment, participants returned in groups of three to five for the first overnight experimental session. They reported at 4 p.m.; car keys were collected from participants who drove to the study site; compliance with pre-laboratory regimens was checked; and, following a standardized dinner, participants were screened for zero breath alcohol (BrAC) and negative pregnancy test (if female). To prepare for a quiz the following morning, at 6 p.m. participants viewed randomly one of two 30-minute video lectures on a public health topic and had an hour to study an accompanying textbook chapter. They viewed the other video lecture the following week. To reduce potential learning effects, participants then practised the computer-based neurocognitive test prior to alcohol administration (Table 2).

Randomization procedures

For the first experimental session, participants received a study ID number and were assigned randomly to beverage (placebo or alcohol); they received the other beverage the following week. For safety reasons, no more than three of the five participants received alcohol on any given night. To maintain double blinding, the individual who prepared beverages and conducted breath tests had no other contact with participants; all other study assistants working directly with participants were unaware of participants' beverage assignments. Participants were told there was a 50–50 chance of receiving alcohol the first night and they were instructed not to inspect or taste each others' drinks or discuss the beverage they received.

Beverage administration procedures

Alcoholic beverage administration targeted 0.12 g% BrAC, adjusting the alcohol per kilogram of body weight for sex (1.068 g/kg body weight for men and 0.915 g/kg for women), as per Friel *et al.* [54]. Males received a mean of 1609.07 (SD: 288.55) ml of beverage (range: 1052.20–2308.00), or the equivalent of 6.75 12-oz cans of regular beer (at 4.82% alcohol by volume); females received a mean of 1122.09 (SD: 178.48) ml of beverage (range: 683.3–1606.60), or the equivalent of 4.72 12-oz cans of regular beer.

Beer controlled with non-alcoholic beer has been shown to be one of the two most effective beverage combinations for disguising placebo [55]. Beer was chosen because most young men and women find it palatable. Elephant Beer™ (Carlsberg, Copenhagen V, Denmark) with 7.2% alcohol and Clausthaler™ non-alcoholic beer (Radeberger Gruppe KG, Frankfurt am Main, Germany) were the beverages. High alcohol beer reduces the volume required to achieve the targeted BrAC. Beverage administration began 4 hours after eating and went from 8.45 p.m. to 9.45 p.m. (up to 10.00 p.m. as needed). Participants were told the total number of cups of beverage they were to consume in an hour. They were asked to drink the first two cups (330–340 ml) quickly and to pace the rest over the time allowed. Participants were breath tested 15 minutes after completing their beverage. If participants randomized to alcohol did not reach 0.12 g% BrAC, the ratio of obtained versus targeted BrAC was used to estimate the additional amount of beer to be administered. To maintain blinding, some of the placebo participants were given a matched extra dose of non-alcoholic beer. After participants finished drinking, they were breath tested every 15 minutes prior to bedtime, with the last BrAC measurement recorded 5 minutes before lights out.

Following beverage administration and a 30-minute absorption period, participants completed questionnaires, received snacks and prepared for bed. Participants had an 8-hour opportunity to sleep (no lights or television and cellphones turned off) between 11 p.m. and 7 a.m. in an individual bedroom with bathroom. They were monitored throughout the night for safety by an emergency medical technician (EMT).

At 7 a.m. participants were awakened, breath-tested and served breakfast (no caffeine). They then completed a questionnaire assessing mood state and, at 8 a.m., started testing. Sleep inertia during the first 30 minutes after waking is likely to impair performance [56]; allowing an hour before performance testing avoids this. To avoid confounding by alcohol remaining in the blood, performance testing was delayed, if necessary, until BrAC reached <0.00 g%. Participants were dismissed from this session at approximately 11.30 a.m. They were given an additional mood assessment questionnaire in a self-addressed, postage-paid return envelope and asked to complete it at 5 p.m. that day and mail it back to the study coordinator. One week later they returned for the second experimental session, identical except for beverage, video lecture and the standardized test version.

Individual difference measures

Recent drinking practice was estimated using a two-item alcohol use questionnaire: (i) 'Considering all your drinking times in the past 30 days, about how often did you have any beer, wine or liquor?', Likert-rated from 1 'once a day' to 7, 'did not drink', with each point anchored; and (ii) 'In the past 30 days, on a typical day that you drank, about how much did you have to drink in one day?', rated from 1 to 8, with choices of one to seven drinks and 'eight or more drinks'. (One drink was defined as 12 ounces of beer or wine cooler, 4 oz of wine or 1 oz of liquor.) Average daily volume (ADV) was calculated as the product of these. We also collected information on family history of drinking problems using the Family History Tree questionnaire developed by Mann *et al.* [57] and on age of drinking onset. These data are presented in Table 1, but were not included in th analyses.

Dependent measures of objective effects

Overview

Two tests of academic performance were used. Short-term recall was assessed by a quiz on a lecture delivered prior to beverage administration. Versions of the Graduate Record Examinations© (GREs) (Educational Testing Service, Princeton, NJ) were used to measure verbal and quantitative skills that have been acquired over a long period of time. Two methods of assessing neurocognitive performance were used: the Neurobehavioral Evaluation System (NES3), a neurocognitive battery; and the Psychomotor Vigilance Task (PVT), a measure of sustained attention/reaction-time.

Lecture quiz

First we administered a 30-question quiz based on the videotaped lecture and associated reading presented the day before. Two lectures and readings were used in counterbalanced order. The two lectures were based on chapters from a public health text, *Introduction to Public Health* [58]: Chapter 15, 'Tobacco: Public Health Threat Number One' and Chapter 16, 'Diet and Activity: Public Health Threat Number Two'. Quiz questions were derived from the teacher's guide. The quizzes were pilot-tested previously with 50 college students to ensure a normal distribution of scores.

GREs

After the quiz, we administered two parts of the GRE's General Test: a 30-minute verbal section (ability to discern, comprehend and analyze words, sentences and written passages) and a 45-minute quantitative section (basic mathematical skills, elementary mathematical concepts and ability to reason and to solve quantitative problems) in four broad content areas: arithmetic, algebra, geometry and data analysis [59]. Two different, but comparable, computer-administered and computer-scored tests were used, with order randomized by individual.

For assessments, participants had their own carrels and were monitored to ensure that they did not communicate. To enhance motivation, participants who scored in the top 50% of national averages on both sections received up to four complimentary movie tickets (two per study week). Participants were not informed of their scores or awarded tickets until they had completed the study.

NES3

The NES3 is a computer-assisted battery of cognitive tests validated for cognitive impairment [60]. As primary measures, we selected nine tests requiring speed, sustained attention or sustained attention/reaction-time, tests most apt to be affected the day after intoxication [61]. For manual dexterity tests that tested each hand individually, we used the test for the preferred hand; for tests that had forward and backward versions, we used the more difficult backward versions. The following tests assessed speed: Finger Tapping Test, preferred hand (FTT-P) (assesses manual motor speed and dexterity); and Sequences Test A, latency (ST-A-L); Digit-Symbol Test, latency (DST-L); Pattern Memory Test, latency (PMT-L) (all assessing speed of cognitive processing). The following tests assessed sustained attention: Auditory Digit Span Test, backwards (ADST-B); Adaptive Paced Auditory Serial Addition Test, number correct (APASAT-C); Visual Span Test, backward (VST-B); Pattern Memory Test, number correct (PMT-C). The Continuous Performance Test (CPT) measures both sustained attention and reaction-time.

PVT

As an additional test of sustained attention/reaction-time, we used the Psychomotor Vigilance Task [62] (Ambulatory Monitoring, Inc, Ardsley, NY, USA). On this hand-held unit participants press a button with their preferred hand as quickly as possible in response to numbers scrolling on an LCD screen, with a random 3–7-second interstimulus interval. Response time is counted in milliseconds. A solid-state storage unit collects data for downloading to a PC. The recorded outcome variable is median reaction-time.

Exploratory measures

As exploratory measures, we administered an additional nine NES-3 tests: FTT (non-preferred hand); ST (backward); ADST-F (forward); APASAT (stimulus response rate); VST (forward); VT (Vocabulary Test, a measure of general verbal ability); LOT (Line Orientation Test, number correct and latency, both measures of attention to visiospatial information); and LL (List Learning, a measure of quantitative aspects of several components of verbal learning and memory).

Dependent measures of subjective effects

Mood

Because the residual effects of alcohol on mood state might be salient to college students, we also measured next-day mood in both the morning and the afternoon. To assess mood, we used the Profile of Mood State Brief Form (POMS) [63], a validated self-administered questionnaire with 30 adjectives [each rated on a five-point Likert scale, from 0 (not at all) to 4 (extremely)]. These comprise six domains: fatigue–inertia (F); tension–anxiety (T); depression–dejection (D); anger–hostility (A); confusion–bewilderment (C); and vigor–activity (V). Only total mood disturbance score [(F+ T+D+A +C)-V] was scored for analyses because we had no hypotheses about individual mood domains.

Self-rated performance

To assess participants' perceptions of their performance on the morning quiz and GRE tests, they completed ratings of subjective performance, with every point anchored: 'Overall, how would you rate your performance on the test that you just completed?'. Response categories were: 1 = 'very poor'; 2 = 'poor'; 3 = 'good'; 4 = 'very good'; and 5 = 'excellent'.

Hangover

The Acute Hangover Scale (AHS) [64], developed based on empirical hangover data [36,65,66], consists of eight validated symptoms plus 'hangover' rated from 0, 'none' to 7, 'incapacitating' on anchored Likert-type scales. The nine items form a reliable and valid scale, scored using the mean.

Alcohol Administration Manipulation checks

An AlcoSensor-4 (Intoximeters, Inc., St Louis, MO, USA) was used for breath testing. Following beverage adminis-

tration, participants were asked to estimate their blood alcohol concentration on a scale ranging from 0 to 0.15 g%.

Statistical power

With a target enrollment of 200 participants, our study had 99% power of detecting the anticipated medium-sized effect of alcohol on next-day academic test performance ($d = 0.52$), a value derived from our previous studies. For comparison of the effects of alcohol versus placebo in females versus males, the study had 80% power of detecting a difference.

Data analysis approach

All measures were examined for normality and outliers, using the criteria set forth by Hoaglin *et al.* [67]. Outliers were recoded following recommendations by Tabachnick & Fidell [68]. Among the primary outcomes measures, there was one outlier for both the GRE verbal and GRE quantitative scores and five outliers for the quiz score.

Differences in outcomes following consumption of alcohol versus placebo were tested through mixed-effects regression models for repeated-measures data [69]. Our primary interest was in differences by experimental condition (alcohol versus placebo, a within-subjects factor). We controlled for randomly assigned order of beverage administration by including a session variable (indicating a first or second study evening, a within-subject factor) and also controlled for gender (a between-subject factor). Differences in alcohol effects for males and females were tested through the interaction between experimental condition and gender, and all other two-way and three-way interactions were also included in the model. Where significant interactions were found between experimental condition and gender, within-gender alcohol effects were tested through model contrasts.

Comparisonwise *P*-values are reported. When considering multiple testing issues, we grouped study outcomes as measures of: (i) academic performance (one quiz and two GRE scores); (ii) 10 primary neurocognitive performance measures (including the PVT); (iii) nine exploratory neurocognitive performance measures; (iv) mood state measures (a.m. and p.m. assessments); and (v) self-reported performance (one for the quiz and one for the two GRE scores). Analyses are interpreted to indicate an alcohol effect if either the main effect of beverage, or the interaction between experimental condition and gender, are significant. To account formally for multiple comparisons using a Bonferroni adjustment, comparisonwise *P*-values of 0.008 (academics) 0.0025 (primary neurocognitive) 0.0028 (exploratory neurocognitive) and 0.0125 (mood state and self-rated performance) would be required. Because Bonferroni is known to overcorrect, we used an $\alpha = 0.005$ throughout our analyses.

Although formal analyses were based on mixed effects regression models, rather than simple differences by beverage condition, difference scores and their standard deviations are presented for ease of interpretation. Differences in performance are also described as standardized effect sizes, calculated as the difference in mean performance under alcohol and placebo divided by the standard deviation of the difference scores (Cohen's *d*) [70]. Cohen [70] considers effect sizes (*d*) of 0.2, 0.5 and 0.8 as small, moderate and large, respectively.

RESULTS

Participant enrollment

Four hundred and thirteen participants were screened; 364 (88%) were eligible. Of these, 239 (65%) appeared for their scheduled experimental session, and of these 196 (82%) completed the study. Three of the 196 participants who completed the study were excluded from analyses because their maximum breath alcohol measures did not reach the minimum BrAC level (.09 g%). Seventy per cent of participants reported some hangover on the morning following alcohol administration. The mean AHS score was significantly higher under alcohol condition, relative to placebo condition (Table 1).

Objective performance outcomes

The morning after beverage administration, neither the quiz scores on the prior day's lecture nor the two GRE scores differed by beverage condition; effect sizes were close to zero (<0.06). None of the academic performance outcomes showed significant beverage–order or gender–beverage interactions (Table 3).

Of the nine primary NES3 measures, VST-B was significantly different by beverage. PMT-C showed significant gender by beverage interaction ($P = 0.032$); females performed worse (borderline significant) under alcohol condition, relative to placebo, but for males there was no difference. No interactions of beverage with order were significant. The morning after beverage administration, median attention/reaction-time scores, as measured by the PVT, were significantly longer under the alcohol condition, relative to the placebo condition (Table 4). Of the exploratory neurocognitive tests, none was significantly different by beverage condition at our α level.

Dependent measures of subjective effects

Mood

The day after beverage administration, the mean total mood disturbance score was significantly worse under

Table 3 Academic performance outcomes by experimental condition.

	Measure	*n*	*Alcohol*	*Placebo*	*Difference (SD)*	*Effect Size (d)*	*P-value*
GRE Raw Scores	GRE verbal	193	495.39 (87.79)	497.62 (86.43)	−2.23 (61.02)	0.04	NS
	GRE quantitative	193	615.75 (98.92)	612.38 (94.64)	+3.37 (62.57)	0.05	NS
Quiz no. correct		193	24.70 (2.26)	24.59 (2.48)	+0.11 (2.65)	0.04	NS

All *P*-values are based on mixed-effects models controlling for gender and session number. The interaction of gender and dose was tested in each model and found to be non-significant. GRE: Graduate Record Examinations; NS: not significant; SD: standard deviation.

Table 4 Neurobehavioral Evaluation System-3 and PVT outcomes by beverage condition.

NES3 outcomes	*n*	*Alcohol*	*Placebo*	*Difference (SD)*	*Effect size (d)*	*P-value*
Tests requiring speed						
Finger Tapping Test: mean number of taps, preferred hand (FTT-P)	188	59.68 (7.11)	60.12 (7.24)	−0.44 (4.73)	0.09	NS
Sequences Test (ST-A-L)						
Sequence A: latency (ms)[a]	188	14.35 (2.66)	14.48 (3.02)	−0.13 (2.59)	0.05	NS
Digit-Symbol Test (DST-L)						
Latency (ms)[b]	188	80.02 (9.53)	79.53 (9.22)	+0.49 (6.63)	0.07	NS
Pattern Memory Test (PMT-L)						
Average response latency for correct items (seconds)	188	3.17 (0.85)	3.15 (0.90)	+0.01 (0.71)	0.02	NS
Tests requiring sustained attention						
Auditory Digit Span Test (ADST-B)[c]						
Maximum span backward	188	6.25 (1.40)	6.16 (1.42)	+0.09 (1.40)	0.06	NS
Adaptive Paced Auditory Serial Addition Test (APASAT-C)						
Number correct	184	94.92 (3.42)	95.06 (3.19)	−0.14 (2.86)	0.05	NS
Visual Span Test (VST-B)						
Maximum span backward	186	5.41 (0.89)	5.67 (1.16)	−0.26 (1.22)	0.21	0.004
Pattern Memory Test (PMT-C)						
Number correct						
Male	103	16.14 (2.90)	16.06 (2.36)	+0.08 (2.65)	0.03	NS
Female	85	15.26 (2.74)	16.12 (2.12)	−0.86 (2.70)	0.32	0.004
Tests requiring sustained attention and reaction-time						
Continuous performance test (CPT)						
Reaction-time (ms)	187	378.77 (35.48)	375.98 (35.82)	+2.78 (22.47)	0.12	NS
Psychomotor vigilance test (PVT)						
Median reaction-time (ms)	190	223.40 (22.81)	218.57 (20.25)	+4.83 (15.08)	0.32	0.000

All *P*-values are based on mixed-effects models controlling for gender and session number. The interaction of gender and dose was tested in each model. If interaction found to be significant, results were presented by gender. [a]Maximum time permitted to complete sequence A: 60 seconds; sequence B: 120 seconds. [b]Maximum time permitted to complete digit/symbol test: 180 seconds. [c]Valid range of span scores for the forward condition: 3–9; backward condition: 2–8. NS: not significant; SD: standard deviation.

alcohol condition, relative to placebo condition, in both the morning and the afternoon (Table 5).

Self-rated performance

Participants tended to rate their performance on the academic tests as worse under alcohol condition, compared to placebo condition. These differences were significant for self-rated performance on the quiz and GREs (Table 5). Participants' mean estimates of their BrACs following beverage administration were 0.006 g% and 0.098 g% under placebo and alcohol conditions, respectively.

DISCUSSION

College students' test-taking performance was not affected significantly on the morning after intoxication. Significant decrements in some laboratory tests of neu-

Table 5 Subjective measures by beverage condition.

Profile of Mood States (POMS) (higher scores reflect more negative mood state)

Measure	*n*	*Alcohol*	*Placebo*	*Difference (SD)*	*Effect Size (d)*	*P-value*
Morning: total mood disturbance score	193	6.71 (9.41)	1.90 (7.20)	+4.81 (7.95)	0.60	0.000
Afternoon: total mood disturbance score	153	4.30 (10.19)	1.93 (8.39)	+2.37 (8.72)	0.27	0.001
Self-rated performance						
Quiz performance	185	3.43 (0.77)	3.61 (0.79)	−0.18 (0.95)	0.19	0.005
GRE performance	188	2.48 (0.69)	2.65 (0.68)	−0.18 (0.76)	0.23	0.002

All *P*-values are based on mixed-effects models controlling for gender and session number. The interaction of gender and dose was tested in each model and found to be non-significant. GRE: Graduate Record Examinations; SD: standard deviation.

rocognitive function were observed on the morning after alcohol. The NES3 was administered to increase understanding of academic performance effects, should they be found. Under placebo condition, participants' NES3 performance scores were normative and most tests showed no alcohol effects. The pattern of residual alcohol effects we found clustered around visuospatial, motor function and attention/reaction-time deficits. These effects may not be central to performance on multiple choice tests based on recall and recognition, but may affect other types of academic performance (unmeasured by our study), such as essay-writing and problem-solving requiring higher-order cognitive skills, as well as safety-related performance such as ability to process information and respond quickly to unexpected events when driving or operating machinery. Mood states, both in the morning and afternoon, were significantly worse on the day after alcohol. Similarly, participants tended to rate their test-taking performance as significantly worse on the day after alcohol relative to placebo, even though no impairment in academic performance was actually observed.

We do not believe our outcomes were artifacts of participant motivation. The GRE scores were comparable to recent norms, with about 60% of participants scoring in the top 50th percentile of the national distribution. Similarly, the mean quiz scores were about 83%, high enough to indicate participant motivation, but low enough to suggest that the quizzes were not too easy (i.e. no ceiling effect). We also do not believe that participant blinding, which can be problematic at high alcohol doses, affected results because the bias would be away from the null hypothesis and we did not find differences on the primary outcome variables (academic test-taking performance). Although our procedures called for abstinence from recreational drugs 24 hours prior to experimental sessions, we used only self-report to check drug-use compliance. Moreover, we did not screen for, or document, drug-use history. Thus, participants' undisclosed drug use prior to experimental sessions could have. If so, there was no consistent effect, as some outcomes were affected significantly on the day after alcohol and others were not.

Although the morning and afternoon mood scores were significantly worse following the alcohol condition, these results may have been driven in part by fatigue resulting from alcohol's sleep-disturbing effects [36,71–73].

While our findings are discordant with results of survey studies that find associations between alcohol use and academic problems, these studies are potentially confounded in that a third factor (e.g. personality) may cause both excessive drinking and academic difficulties and causal order is unknown (i.e. academic difficulties could lead to excessive drinking). Our findings are consistent, however, with a study on the effects of intoxication on next-day occupational performance [33]. In that study, merchant marine cadets' performance on a diesel engine simulator was not affected significantly, relative to placebo, on the morning after intoxication (mean BrAC.115 g%), but self-rated performance was significantly worse. Similarly, another laboratory study found measures of combined attention and reaction-time to be the only neurocognitive measures affected on the morning after 0.11 g% BrAC [74].

We do not conclude, however, that excessive drinking is not a risk factor for academic problems. It is possible that a higher alcohol dose would have affected next-day academic test scores. Moreover, test-taking is only one factor in academic success. Study habits, motivation and class attendance also contribute to academic performance; each of these could be affected by intoxication. When drinking leads to staying up too late, sleeping in or getting too little sleep, it can disrupt next-morning attendance or focus. Moreover, we did not measure whether learning skills were impaired on the day after intoxication. The neurocognitive measures that were affected negatively on the day after alcohol could be related to the ability to process new information effectively. By neces-

sity, all participants were ≥21 years of age and thus were college juniors, seniors or recent graduates. It is possible that over the course of their education students develop skills that allow them to perform well on multiple-choice tests despite neurocognitive impairment resulting from intoxication the previous night. Accordingly, had our participants been freshmen or sophomores, they might have performed worse under alcohol, relative to placebo, condition. We excluded volunteers who had not engaged in recent binge drinking or who were at risk for alcohol dependence. It is possible that these excluded drinkers might be more susceptible to alcohol-related problems with test-taking. Nonetheless, in surveys almost half of college students report binge drinking and presumably most of these have not developed alcohol dependence. Thus, we believe that our findings are relevant to a substantial proportion of college students.

Clinical trials registration

ClinicalTrials.Gov Identifier: NCT00183170

Declarations of interest

None.

Acknowledgements

We wish to acknowledge the invaluable contribution of Daniel J. Gottlieb, MD, who provided clinical support and expertise to this study. This research was supported by: (1) the Youth Alcohol Prevention Center, Boston University School of Public Health, with funding from NIAAA grant # P60 AA013759-01; and (2) by the National Center for Research Resources (NCRR), grant # M01 RR00533, a component of the National Institutes of Health (NIH). Its contents are solely the responsibility of the authors and do not necessarily represent the official view of the NCRR or NIH.

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