# Acute and Chronic Effects of Alcohol on Trail Making Test Performance Among Underage Drinkers in a Field Setting

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**ABSTRACT. Objective:** Alcohol's effects on executive functioning are well documented. Research in this area has provided much information on both the acute and chronic effects of alcohol on processes such as working memory and mental flexibility. However, most research on the acute effects of alcohol is conducted with individuals older than 21 years of age. Using field recruitment methods can provide unique empirical data on the acute effects of alcohol on an underage population. **Method:** The current study examined the independent effects of acute alcohol intoxication (measured by breath alcohol content) and chronic alcohol use (measured by years drinking) on a test of visuomotor performance and mental flexibility (Trail Making Test) among 91 drinkers ages 18–20 years recruited from a field setting. **Results:** Results show that breath alcohol predicts performance on Trails B, but not on Trails A, and that years drinking, above and beyond acute intoxication, predicts poorer performance on both Trails A and B. **Conclusions:** These data suggest that, independent of the acute effects of alcohol, chronic alcohol consumption has deleterious effects on executive functioning processes among underage drinkers. Our discussion focuses on the importance of these data in describing the effect of alcohol on adolescents and the potential for engaging in risky behavior while intoxicated. (*J. Stud. Alcohol Drugs, 74,* 635–641, 2013)

ALCOHOL ACUTELY AFFECTS component processes of executive functioning, including planning (Montgomery et al., 2011; Peterson et al., 1990; Weissenborn and Duka, 2003), set-shifting (Guillot et al., 2010; Lyvers and Maltzman, 1991), response inhibition (Reynolds et al., 2006), and working memory (Grattan-Miscio and Vogel-Sprott, 2005; Schweizer et al., 2006). In addition, there are residual effects of alcohol on executive function, such that chronic use of alcohol leads to deficits in performance on tasks that measure the same constructs (Cairney et al., 2007; Fernández-Serrano et al., 2011; Green et al., 2010; Hildebrandt et al., 2004).

The effects of alcohol may be particularly detrimental to adolescents (Crews et al., 2007; Masten et al., 2008), because adolescence is a period marked by rapid and extreme neurobiological change (Spear, 2000). Although this is a time when individuals gain greater access to certain executive functions, such as attentional control (Anderson et al., 2001) and working memory (Zald and Iacono, 1998), adolescents still perform more poorly than do adults on a number of different tests of executive function (for a review, see Blakemore and Choudhury, 2006). Understanding the ways in which adolescents are affected, both acutely and chronically, by alcohol is an area of research that requires more attention.

Because of legal and ethical restrictions in the United States, there is a relative dearth of empirical data on the acute effects of alcohol in individuals younger than 21 years of age. Research from abroad, which allows for alcohol administration to individuals age 18 and older, indicates that there are acute, deleterious effects of alcohol on planning (Montgomery et al., 2011) and on the inhibition of a prepotent response (Rose and Duka, 2008, Study 1), although results are equivocal, with some researchers finding that alcohol actually enhances performance on tasks of response inhibition (Birak et al., 2010). In addition, there is a complete absence of research that focuses on the acute effects of alcohol in only those individuals who are younger than age 21 years.

There is a growing body of research based on data gathered from drinkers in naturalistic settings (Celio et al., 2011; Reingle et al., 2009; Thombs et al., 2003, 2009a, 2009b).

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Data collected in field settings indicate that individuals recruited in bars or while driving after drinking display deficits in executive functioning, but research in this area has been completed with adults with a wide range of ages—from 18 to "over 50" across studies completed by Domingues and colleagues (2009) and Lyvers and Tobias-Webb (2010). Examining the role of acute alcohol intoxication in a specifically underage sample will help to clarify the effect of alcohol on executive functioning in this vulnerable population.

The current study examined the independent influence of (a) acute alcohol intoxication and (b) chronicity of alcohol use on visuomotor performance and mental flexibility in a field study sample. We hypothesized that both acute alcohol intoxication and years drinking would affect performance on a measure of executive functioning among younger drinkers.

## Method

### *Participants and study design*

The protocol was approved by the university institutional review board and in conjunction with local law enforcement. That is, the local police department approved of the study but otherwise had no direct involvement with recruitment, interviewing, surveys, or testing. It is standard practice for police officers to be present and visible in the city's downtown bar district, but police did not interact with study staff or active participants. Data were collected over more than 2 years during field recruitment of individuals in the downtown area of a mid-sized city in upstate New York. The study design and methods are described in detail elsewhere (Celio et al., 2011). Briefly, the study team, which included 8–12 trained research assistants, recruited individuals between the hours of 11:00 P.M. and 2:30 A.M. on Thursday and Friday nights in the downtown bar district of this college city. Individuals displaying overt symptoms of severe impairment (e.g., grossly incoherent speech, inability to stand) were not approached because such individuals were unable to complete the basic elements of the protocol (e.g., answering questions in interview format, completing a paper-and-pencil survey while standing).

After providing verbal consent, participants (*N* = 247) completed three different tasks: (a) a semistructured interview about their drinking, (b) a paper-and-pencil survey that took approximately 5 minutes to complete, and (c) 8 minutes of neuropsychological testing that took place in a station that was divided into two work areas. Over the course of the study, approximately 30% of individuals approached declined participation.

Participants ages 18–20 years were included in the current study (91 total). Each participant completed a questionnaire packet that assessed relevant demographics, including age and gender, completed one cognitive test (see the *Measures* section below), and provided a breath alcohol reading. The entire protocol took approximately 15 minutes. At the completion of testing, individuals were given a card that provided institutional review board and study contact information, along with a link to a website where they could receive their exact breath alcohol reading after noon the next day. No other rewards or incentives were provided.

### *Measures*

*Breath alcohol concentration (BrAC).* Breath samples were collected from participants using handheld BrAC test units (CMI Intoxilyzer 400PA; CMI, Inc., Owensboro, KY; manufactured in 2009), which were calibrated monthly according to manufacturer specifications.

*Chronicity of alcohol use.* Among the questions asked in the questionnaire packet was the open-ended question, "What was your age during the first five times you drank alcohol?" The participant's response to this item was subtracted from his or her current age, which resulted in an index of "total years drinking."

*Visuomotor performance and mental flexibility.* The Trail Making Test (TMT; Army Individual Test Battery, 1944; Reitan, 1958) is a valid, reliable test of neurocognitive function that requires individuals to connect numbered circles in ascending order using a pencil and paper (Trails A), and then to connect numbered circles and alphabet letters in ascending, alternating order using a pencil and paper (Trails B). Both Trails A and B are intended to be completed as quickly and as accurately as possible. Whereas Trails A is primarily a task of visuomotor performance (Spreen and Strauss, 1991), Trails B primarily measures working memory (Sánchez-Cubillo et al., 2009) and mental flexibility (Strauss et al., 2006). The TMT composite score (Trails B completion time minus Trails A completion time; see Lezak et al., 2004) was also used to remove the speed element from the test evaluation, resulting in a more refined index of mental flexibility (Corrigan and Hinkeldey, 1987). Higher scores on Trails A and B and the composite score (B − A) reflected more time needed to complete the task, and hence, poorer performance.

*Drinking behavior.* The Alcohol Use Disorders Identification Test (AUDIT; Babor et al., 2001) was included as a self-report measure of overall risk associated with alcohol use during the past year. The AUDIT yields a score ranging from 0 (*no alcohol-related risk*) to 40 (*maximum alcohol-related risk*); scores greater than 8 suggest a hazardous drinking pattern and possible alcohol use disorder. The AUDIT has been shown to provide reliable reports under naturalistic conditions (Celio et al., 2011).

### *Statistical analyses*

Descriptive statistics and graphics were used to examine each variable of interest and determine whether it was appropriate for parametric analyses. Because none of these vari-

Table 1. Sample demographics and descriptive statistics

| | Men ($n$ = 56) | | Women ($n$ = 35) | | |
|---|---|---|---|---|---|
| Variable | *M* (*SD*) | Range | *M* (*SD*) | Range | *p* |
| Age, in years | 19.39 (0.78) | 18–20 | 19.34 (0.77) | 18–20 | .77 |
| Age at drinking onset, in years | 15.16 (1.74) | 10–18 | 15.46 (1.85) | 12–19 | .44 |
| Years drinking[a] | 4.23 (1.84) | 0–8 | 3.89 (1.97) | 1–8 | .40 |
| AUDIT total score | 15.29 (5.80) | 2–28 | 13.46 (7.27) | 0–32 | .19 |
| BrAC | .093 (.061) | .000–.287 | .085 (.067) | .000–.269 | .60 |
| Trails A[b] | 24.34 (7.78) | 12–49 | 25.83 (11.67) | 9–58 | .47 |
| Trails B[c] | 62.86 (25.23) | 25–132 | 63.74 (25.98) | 27–143 | .87 |
| TMT composite[d] | 38.52 (22.37) | 6–95 | 37.91 (19.45) | 10–96 | .90 |

*Notes:* Independent-samples *t* tests used for group comparison. AUDIT = Alcohol Use Disorders Identification Test; BrAC = breath alcohol concentration; TMT = Trail Making Test. [a]Years drinking = the difference (in years) between the participant's current age and their age during the first five times drinking; [b]Trails A = the completion time (in seconds) for part A of the Trail Making Test; [c]Trails B = the completion time (in seconds) for part B of the Trail Making Test; [d]TMT composite = the Trail Making Test composite score (i.e., Trails B − Trails A). Longer times on Trails A, Trails B, and TMT composite are associated with worse performance.

ables demonstrated gross violations of normality, a bivariate correlation examining the associations among the variables of interest was completed. Multiple regression analysis was used to test whether AUDIT total score, BrAC, and total years drinking predicted Trails performance. All independent variables were force entered into the model simultaneously; therefore, order of entry is not a factor when interpreting the overall results. Separate analyses were run for Trails A, Trails B, and the composite score. The model for each regression analysis was as follows: age was entered as an a priori covariate; AUDIT total score, BrAC, and total years drinking were entered as the primary independent variables of interest.

## Results

### *Sample demographics and descriptive statistics*

Participants in this sample were predominantly male (62%), with a mean age of 19.37 years (range: 18–20). The mean age at onset for drinking was 15.27 years (*SD* = 1.77, range: 10–19), and mean number of years drinking was 4.10 (*SD* = 1.89, range: 0–8). The current sample was characterized by a moderate to high level of alcohol-related risk, with a mean AUDIT score of 14.58 (*SD* = 6.43, range: 0–32). With regard to current episodic drinking, the mean BrAC for the sample was .090% (*SD* = .063, range: .000–.287), which included eight individuals with BrACs of .000%. Those eight reported having between zero and five drinks before arriving in the bar district that night. When the individuals who both (a) had a BrAC of .000% and (b) drank zero drinks ($n$ = 3) are removed from the sample, the mean BrAC and corresponding standard deviation do not change. In addition, when correlations and regression analyses are rerun with the nondrinkers removed, the pattern of results does not change. Thus, analyses on the full sample of 91 are reported. Mean time to complete Trails A was 24.91 seconds (*SD* = 9.42; range: 9–58) and 63.20 seconds to complete Trails B (*SD* = 25.38, range: 25–143). The mean TMT composite score for the sample was 38.39 (*SD* = 21.19, range: 6–96). See Table 1 for a comparison of sample demographics and summary statistics by gender.

First-order correlations between the variables of interest are presented in Table 2. With regard to demographics, participants' current age was significantly and negatively correlated with the TMT composite score ($r$ = -.21, $p$ = .04), whereas gender was not significantly correlated with any variables of interest. AUDIT total score was significantly and positively correlated with performance on Trails A ($r$ = .26, $p$ = .01) and Trails B ($r$ = .24, $p$ = .02). As predicted, BrAC was significantly and positively correlated with performance on Trails B ($r$ = .55, $p$ < .001) and the TMT composite score ($r$ = .57, $p$ < .001) and marginally significantly correlated with Trails A ($r$ = .20, $p$ = .052); total years drinking was also positively correlated with the measures of mental flexibility (Trails A: $r$ = .23, $p$ = .03; Trails B: $r$ = .27, $p$ = .01; TMT composite score: $r$ = .22, $p$ = .04).

### *Predicting working memory performance*

Multiple regression analysis was used to test the primary hypothesis that both acute alcohol intoxication and years drinking would affect working memory performance as measured by the TMT. With regard to performance on Trails A, the results of the regression indicated that the complete model explained 13% of the variance ($R^2$ = .13), $F$(4, 86) = 3.26, $p$ = .02. Although age and BrAC were not significant predictors, AUDIT total score ($\beta$ = .20, $p$ = .06) and total years drinking ($\beta$ = .21, $p$ = .06) were marginally significant predictors of performance on Trails A.

TABLE 2. Correlation analysis examining the first-order relationships among the variables of interest

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1. Age | – | | | | | | |
| 2. Gender | -.03 | – | | | | | |
| 3. AUDIT total score | -.00 | -.14 | – | | | | |
| 4. Years drinking[a] | .34** | -.09 | .19 | – | | | |
| 5. BrAC | -.16 | -.06 | .17 | .03 | – | | |
| 6. Trails A[b] | -.02 | .08 | .26* | .23* | .20 | – | |
| 7. Trails B[c] | -.18 | .02 | .24* | .27** | .55** | .59** | – |
| 8. TMT composite[d] | -.21* | -.01 | .17 | .22* | .57** | .27* | .93** |

*Notes:* Gender is a dichotomous categorical variable with 0 indicating male and 1 indicating female. AUDIT = Alcohol Use Disorders Identification Test; BrAC = breath alcohol concentration; TMT = Trail Making Test. [a]Years drinking = the difference (in years) between the participant's current age and their age during the first five times drinking; [b]Trails A = the completion time (in seconds) for part A of the Trail Making Test; [c]Trails B = the completion time (in seconds) for part B of the Trail Making Test; [d]TMT composite = the Trail Making Test composite score (i.e., Trails B − Trails A). Longer times on TMT are associated with worse performance.
$*p < .05$; $**p \leq .01$.

With regard to performance on Trails B, the results of the regression indicated that the complete model explained 41% of the variance ($R^2$ = .41), $F(4, 86) = 14.97$, $p < .001$. AUDIT total score was not a significant predictor in the model. Performance on Trails B was significantly predicted by participant age (β = -.21, $p$ = .02), current BrAC (β = .49, $p < .001$), and total years drinking (β = .31, $p < .001$).

The same pattern of results was observed with regard to the TMT composite score. That is, the complete model explained 41% of the variance ($R^2$ =.40), $F(4, 86) = 14.57$, $p < .001$, and age (β = -.23, $p$ = .02), current BrAC (β = .52, $p < .001$), and total years drinking (β = .28, $p$ = .003) were significant predictors of performance. The complete results of these multiple regression analyses are presented in Table 3.

## Discussion

The current study sought to determine the independent effects of acute alcohol intoxication and chronic alcohol use on a measure of visuomotor performance and mental flexibility in a population of underage drinkers. Consistent with hypotheses, we found that there are acute effects of alcohol on mental flexibility (as measured by Trails B) among a sample of drinkers obtained via field recruitment. However, there were no acute effects of alcohol on visuomotor coordination (Trails A). Chronic alcohol use, independent of acute alcohol intoxication, affected Trails A and B and also affected composite performance (Trails B − A). These findings lend themselves to important conclusions.

First, alcohol did not exert acute effects on the measure of motor performance (Trails A). Previous research has indicated that visuomotor performance is affected by acute alcohol intoxication (Brumback et al., 2007), although this may be the case only for older drinkers. Animal model research implicates adolescence as a time in which individuals are insensitive to the motor-impairing aspects of alcohol (Ramirez and Spear, 2010; White et al., 2002), and our findings could reflect a similar insensitivity in our sample

TABLE 3. Multiple linear regression analyses of working memory performance

| Variable | *B* | *SE* | β | *t* | *p* |
|---|---|---|---|---|---|
| Trail Making Test part A | | | | | |
| Age | -0.81 | 1.33 | -.07 | -0.61 | .54 |
| AUDIT | 0.29 | 0.15 | .20 | 2.05 | .06 |
| BrAC | 22.97 | 15.51 | .15 | 1.53 | .14 |
| Years drinking | 1.04 | 0.55 | .21 | 1.97 | .06 |
| Trail Making Test part B | | | | | |
| Age | -6.99 | 2.96 | -.21 | -2.37 | .02 |
| AUDIT | 0.38 | 0.34 | .10 | 1.11 | .27 |
| BrAC | 196.60 | 34.38 | .49 | 5.72 | <.001 |
| Years drinking | 4.13 | 1.21 | .31 | 3.40 | <.001 |
| Trail Making Test composite score | | | | | |
| Age | -6.18 | 2.48 | -.23 | -2.49 | .02 |
| AUDIT | 0.09 | 0.28 | .03 | 0.31 | .76 |
| BrAC | 173.63 | 28.87 | .52 | 6.02 | <.001 |
| Years drinking | 3.09 | 1.02 | .28 | 3.04 | <.01 |

*Notes:* $R^2$ = .13 for Trails A; $R^2$ = .41 for Trails B; $R^2$ = .40 for Trail Making Test (TMT) composite. Longer times on TMT are associated with worse performance. AUDIT = Alcohol Use Disorders Identification Test; BrAC = breath alcohol concentration.

of underage youth. Although there is a relative dearth of literature examining the motor impairments caused by acute alcohol intoxication in underage drinkers, one study found that a moderate dose of alcohol contributed to enhancements in performance on Trails A among younger, as compared with older, drinkers; this was interpreted as being the result of the stimulating effects of alcohol on the ascending limb or the result of acute intoxication contributing to increased attention toward the task (Gilbertson et al., 2009). It is possible that the participants in the current study were allocating the majority of their attention to the task; however, because of the wide range of breath alcohol measurements in the sample, it is unlikely that all participants were on the ascending limb of the blood alcohol curve, which makes this interpretation less likely.

However, alcohol did acutely affect Trails B, a measure of more complex executive processes, including working memory and mental flexibility. When comparing the completion times of the current sample with similarly aged nonpsychiatric community members' completion times reported in Soukup et al. (1998), we found that the current participants performed similarly on Trails A ($M$ = 24.9 seconds, $SD$ = 9.4), where reported means for individuals between the ages of 15 and 24 are between 21 and 27 seconds. However, the participants in the current study performed markedly more poorly on Trails B ($M$ = 63.2 seconds, $SD$ = 25.4), which has published norms of time to completion of 43–57 seconds (as summarized in Soukup et al., 1998). In other words, compared with a similarly aged sample, the intoxicated individuals in this study took longer to complete Trails B but not Trails A, which is consistent with the interpretation that the acute effects of alcohol on cognitive functioning in adolescents may be limited to more complex functions, while sparing more basic visuomotor capabilities.

These findings are in some ways inconsistent with other findings, which indicate alcohol's failure to affect cognitive processes among younger drinkers. For example, alcohol has failed to affect visuospatial working memory at moderate (.06%; Rose and Duka, 2008) and heavier (.08%; Pihl et al., 2003) doses in samples that included, but unlike the present study were not restricted to, drinkers 18–20 years of age. In addition, there are reports that alcohol does not always affect short-term memory capacity in younger drinkers at moderate (Grattan-Miscio and Vogel-Sprott, 2005) and heavier doses (Tiplady et al., 2009). Thus, although alcohol's acute effects are not always evident in performance on tasks of executive function, alcohol may be affecting only certain complex cognitive processes. This is particularly worrisome because these individuals may not be able to readily identify impairment based on simple motor coordination and will instead show impairment at a time when it is more crucially needed—for example, while driving or attempting to negotiate dangerous or threatening social situations.

These interpretations of Trails A versus B performance contrast with other findings from our laboratory regarding the influence of cognitive and motor impairment on subjective intoxication. In that study (Celio et al., 2013), we found that simple motor performance (as measured by the Finger Tapping Test; Reitan and Wolfson, 1993), and not higher-order cognitive performance (indexed by the TMT composite score; i.e., Trails B – Trails A), was related to subjective intoxication in a sample of drinkers ages 18–33 years. Whereas performance on Trails A is influenced by motor speed, the visual scanning component of Trails A makes it distinctly different from a simple motor task such as finger tapping (which requires minimal visual ability). Taken together, these findings could suggest that when individuals are identifying how intoxicated they feel, they rely on motor cues; however, more complex executive function, while also impaired, is not as salient an indicator to these individuals but nonetheless can have an influence on their behavior. In other words, adolescents might be intoxicated but base their inferences regarding how intoxicated they are on only their motor impairment while having little sense of how impaired their executive functioning is. This might lead them to engage in situations that would benefit from an unimpaired executive system (e.g., choosing to cross a busy street or taking enough care in deciding on which route to walk home). Future research is clearly needed on the time course of impairment among adolescents—for example, does executive impairment precede motor impairment? It would stand to reason that at lower levels of intoxication, if motor coordination is not impaired and individuals are not considering themselves to be too drunk, they could still be exhibiting executive deficits that contribute to dangerous behavior.

Chronic alcohol use was found to exert an independent effect on both parts of the TMT performance while adolescents are under the influence of alcohol. The current findings corroborate a previous report about the cognitive effects of chronic use of alcohol in young people (Hanson et al., 2011) and provide additional information about the independence of chronic alcohol use in predicting impairment. This finding is particularly relevant for adolescents who continue to drink throughout this transitional phase in their lives. Not only does chronic alcohol use impair their capacity to engage in complex cognitive efforts, but it also appears to create a vulnerability that persists, and even exacerbates, the impairment caused by acute intoxication. Adolescents who have already developed a lengthy drinking history may be in need of targeted efforts to remediate the deficits caused by long-term alcohol use.

Several limitations are worth noting. Perhaps the most important limitation to note is that, because of the cross-sectional nature of the data collection, we cannot determine the direction of causality between deficits in executive functioning and alcohol intoxication; we can say only that they are associated. It is possible that individuals who have preexisting cognitive deficits are those who are likely to achieve higher blood alcohol concentrations and to have longer drinking histories. Another limitation is that drinking history was assessed only by measuring years of drinking by subtracting current age from each individual's age when regular alcohol use was initiated. Age and years drinking were correlated, indicating that older participants, not surprisingly, had longer drinking histories, although it is difficult to interpret age effects within the limited age range assessed. The average number of years drinking is only about 4 years; the 2-year difference from the youngest (18 years of age) to oldest (20 years) participants likely reflects a lot in terms of drinking experience, making it difficult to disentangle age and drinking history effects. For careful assessment of age effects, a larger age range would be useful.

In addition, beyond the number of years drinking, we did not probe for the quality of the drinking from the point of initiation of use. That is, we did not assess for quantity and frequency of drinking and how it did or did not change in the years between the first five drinking episodes and the current study. Research suggests that the quality of drinking (e.g., episodes of relatively heavy drinking) leads to more pronounced effects on cognitive function (Parker and Noble, 1977). In addition, repeated withdrawals from alcohol have a more pronounced effect on executive function (Loeber et al., 2009, 2010). Thus, it is possible that some individuals in our sample engaged in more intense drinking than others or went through more withdrawal episodes, and this is not reflected in the current findings. It is reasonable to assume that the age of the sample (younger than 21 years old) precludes a large proportion of these individuals from having experienced a great number of withdrawal episodes, but we did not measure this variable.

Because these data were collected in a field setting and not a laboratory, we also do not have information on whether individuals are on the ascending or descending limb of the alcohol curve. However, laboratory research indicates that individuals may experience acute tolerance to the effects of alcohol in the form of lowered subjective intoxication on the descending limb of the alcohol curve, while performance on tasks of executive function remains impaired (Cromer et al., 2010). Last, although this is not a limitation, it is worthwhile to note that, when working with an underage population of heavy drinkers in a field setting, there are often alarmingly high BrAC readings. All participants who provided a breath sample received standardized feedback about their current risk level, as well as contact information for a community mental health clinic and the university counseling center (for current students). There was also an experienced clinician who was on site at all times during data collection.

In sum, in a field study of underage drinkers, we found that acute alcohol intoxication was associated with performance on tests of working memory (Trails B) and mental flexibility (Trails B – A) but not simple visuomotor performance (Trails A). In addition, we found that years of regular alcohol use was positively related to both of these constructs, above and beyond acute intoxication, with a longer drinking history associated with more impaired function. These findings have implications for prevention efforts among underage drinkers, who may already be experiencing residual deleterious effects of alcohol on elements of executive functioning.

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