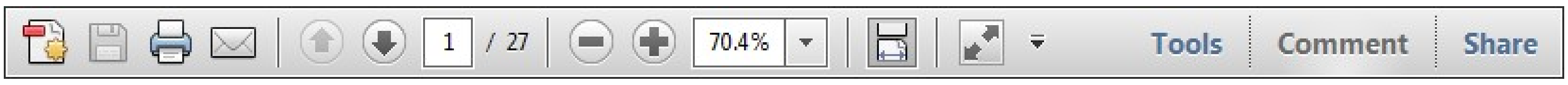
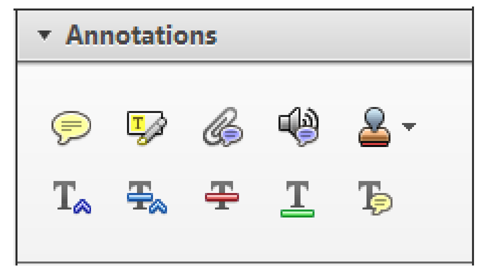
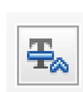
Once you have Acrobat Reader open on your computer, click on the Comment tab at the right of the toolbar:



This will open up a panel down the right side of the document. The majority of tools you will use for annotating your proof will be in the Annotations section, pictured opposite. We've picked out some of these tools below:



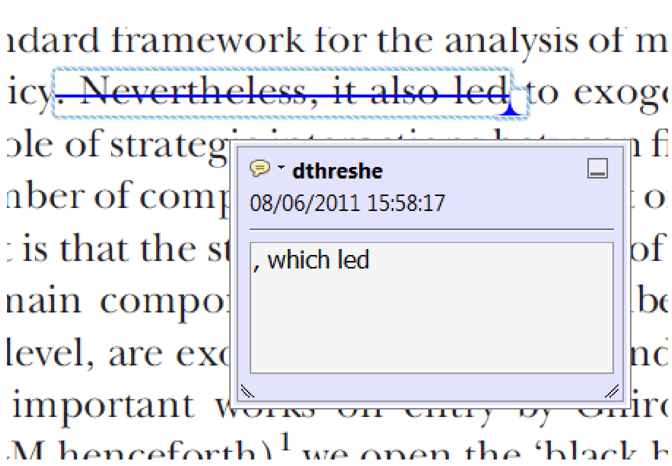
1. Replace (Ins) Tool – for replacing text.



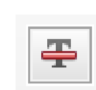
Strikes a line through text and opens up a text box where replacement text can be entered.

How to use it

- Highlight a word or sentence.
- Click on the Replace (Ins) icon in the Annotations section.
- Type the replacement text into the blue box that appears.



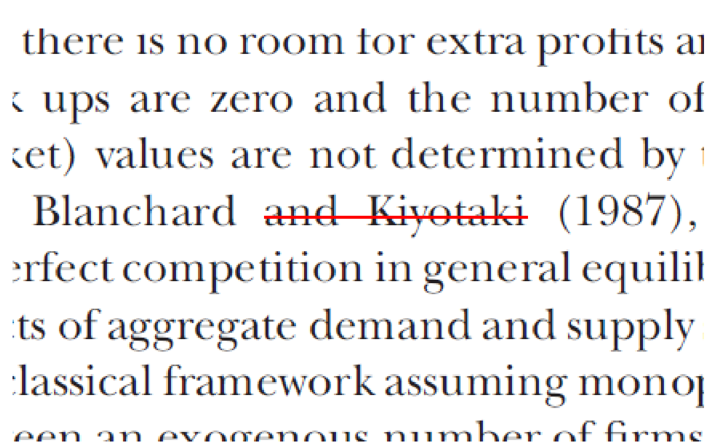
2. Strikethrough (Del) Tool – for deleting text.



Strikes a red line through text that is to be deleted.

How to use it

- Highlight a word or sentence.
- Click on the Strikethrough (Del) icon in the Annotations section.

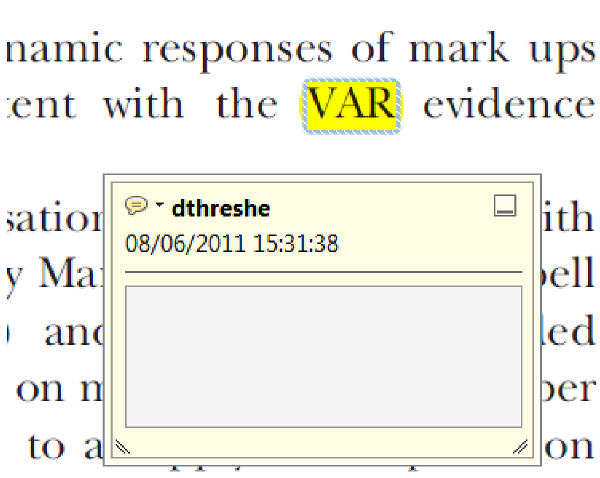


3. Add note to text Tool – for highlighting a section to be changed to bold or italic.

Highlights text in yellow and opens up a text box where comments can be entered.

How to use it

- Highlight the relevant section of text.
- Click on the Add note to text icon in the Annotations section.
- Type instruction on what should be changed regarding the text into the yellow box that appears.

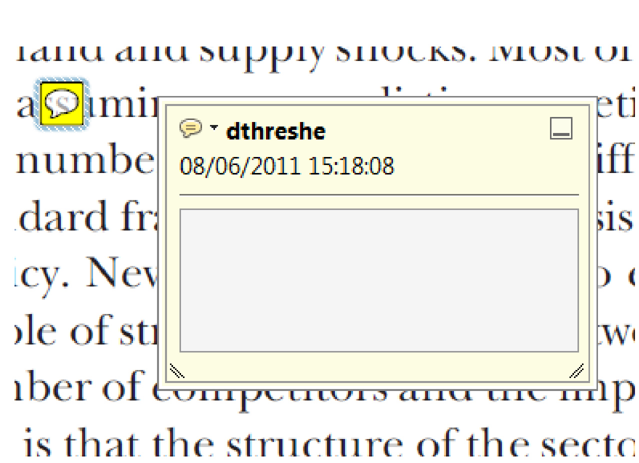


4. Add sticky note Tool – for making notes at specific points in the text.

Marks a point in the proof where a comment needs to be highlighted.

How to use it

- Click on the Add sticky note icon in the Annotations section.
- Click at the point in the proof where the comment should be inserted.
- Type the comment into the yellow box that appears.

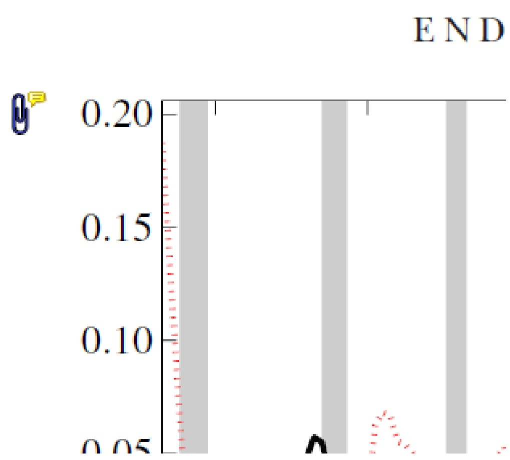


5. Attach File Tool – for inserting large amounts of text or replacement figures.

Inserts an icon linking to the attached file in the appropriate pace in the text.

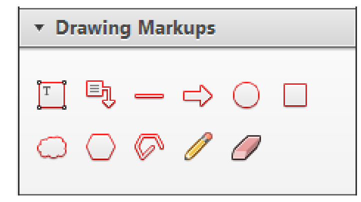
How to use it

- Click on the Attach File icon in the Annotations section.
- Click on the proof to where you'd like the attached file to be linked.
- Select the file to be attached from your computer or network.
- Select the colour and type of icon that will appear in the proof. Click OK.



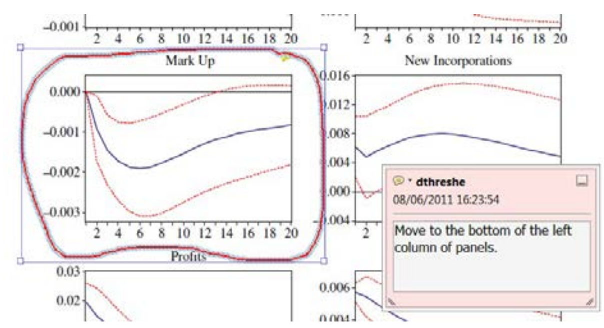
6. Drawing Markups Tools – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks.

Allows shapes, lines and freeform annotations to be drawn on proofs and for comment to be made on these marks.



How to use it

- Click on one of the shapes in the Drawing Markups section.
- Click on the proof at the relevant point and draw the selected shape with the cursor.
- To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
- Double click on the shape and type any text in the red box that appears.



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Alcohol words elicit reactive cognitive control in low-sensitivity drinkers

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Abstract

Previous ERP studies shown support for the idea that alcohol-related stimuli are particularly salient to individuals who report low sensitivity (LS) to alcohol's effects (a known risk factor for alcohol-related problems), leading such stimuli to spontaneously capture their attention and interfere with self-regulatory goal pursuit. The current study investigated LS individuals' use of reactive and proactive cognitive control in response to alcohol-related stimuli. Participants performed an alcohol Stroop task in which they indicated the font color of alcohol- and nonalcohol-related words while ERPs were recorded. The probability of alcohol and nonalcohol words was manipulated to test predictions derived from Dual Mechanisms of Control theory. Among LS individuals, infrequent alcohol-related words elicited slower responses and larger N2 amplitude, consistent with these stimuli eliciting enhanced reactive control responses. Amplitude of the frontal slow wave (FSW) component, associated with proactive control, was marginally larger among LS individuals when alcohol words were more frequent, but response accuracy was lower. These findings demonstrate that LS individuals experience conflict when presented with task-irrelevant alcohol-related stimuli, even in a context where conflict arguably should not be present. Findings further suggest that LS individuals can effectively implement reactive control to deal with this conflict when it is infrequent but have difficulty implementing proactive control in the context of more frequent conflict.

Descriptors: Alcohol sensitivity, Cognitive control, ERPs

Risk for alcohol use disorder (AUD) is influenced by several factors, including variability in the level of response to alcohol (Schuckit et al., 2007; Sher & Wood, 2005). Level of response to alcohol, or alcohol sensitivity, can be characterized as the number of drinks that must be consumed in order to experience various effects of alcohol (Schuckit, 1998; Schuckit, Smith, & Tipp, 1997). The etiologic relevance of alcohol sensitivity for alcohol-related problems is supported by evidence that low sensitivity (LS) predicts development of AUD (for reviews, see Morean & Corbin, 2010; Ray, Mackillop, & Monti, 2010), and that risk associated with LS is dissociable from other known predictors, such as behavioral undercontrol, comorbid psychiatric disorders, and personality (e.g., Trim, Schuckit, & Smith, 2009).

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Despite evidence linking LS with drinking-related problems, the mechanism(s) for this association remain poorly understood. Recently, Fleming and Bartholow (2014) reported impaired inhibitory control in the presence of alcohol-related images among LS drinkers. They found that alcohol-related stimuli requiring the withholding of a behavioral response (infrequent no-go targets) elicited heightened response conflict among LS individuals, relative to their high-sensitivity (HS) counterparts, as seen in the amplitude of the conflict-related N2 component of the ERP (Folstein & Van Petten, 2008). This finding demonstrates that when conflict resolution is necessary, the presence of alcohol cues makes the process more challenging for LS drinkers, presumably because such cues have heightened motivational significance for LS individuals (see also Bartholow, Lust, & Tragresser, 2010; Shin, Hopfiner, Lust, Henry, & Bartholow, 2010).

But might alcohol-related cues alone have the power to create conflict for LS drinkers where none otherwise exists? This issue has potentially important implications for understanding the behavior of at-risk drinkers whose lives can be disrupted by the presence of cues that compel alcohol seeking and use. Imagine someone who has a job interview in 2 hours and happens to pass a bar while walking down the street. Many people would not even notice the bar, let alone contemplate going inside and having a drink to calm their nerves, but the heightened motivational significance of alcohol cues could capture the LS drinker's attention and produce conflict in this scenario. In other words, the presence of alcohol cues might contribute to behavioral dysregulation among LS drinkers by eliciting responses that interfere with pursuit of ongoing goals.

A number of investigators have utilized a modified version of the Stroop task, known as the alcohol Stroop, to examine how attentional bias to alcohol stimuli interferes with cognitive control among individuals at risk for AUD (Cox, Yeates, & Regan, 1999; Field, Christiansen, Cole, & Goudie, 2007). A traditional color-word Stroop task, in which respondents must name the ink color of color names (e.g., "RED" in blue ink), produces conflict for anyone who routinely reads English words. In contrast, the alcohol Stroop only produces conflict among individuals for whom alcohol is particularly motivationally salient. Consistent with this idea, studies using this task have found that compared to light drinkers and healthy controls, heavy drinkers and alcohol-dependent individuals are slower to name the font color of alcohol-related words, indicating an attentional bias for alcohol that interferes with the ability to perform the color-naming task (Field et al., 2007; Johnsen, Laberg, Cox, Vaksdal, & Hugdahl, 1994; Murphy & Garavan, 2011). The current study used an alcohol Stroop task to determine whether the mere presence of alcohol-related stimuli creates conflict for LS individuals.

Cognitive Control and Its Neural Correlates

The Dual Mechanisms of Control (DMC) theory (see Braver, 2012; De Pisapia & Braver, 2006) proposes that cognitive control consists of two operating modes, proactive and reactive. Proactive control serves to bias information processing toward current goals prior to the occurrence of conflict by maintaining task sets over time; reactive control activates task goals once conflict is detected, marshaling efforts to overcome it (Braver, 2012). Varying the proportion of congruent (e.g., the word RED in red ink) and incongruent trials (e.g., the word RED in green ink) in the Stroop task influences the balance of power between these two modes of control (De Pisapia & Braver, 2006). When most of the trials are congruent, individuals may conserve resources by relying on reactive control to handle infrequent conflict when it arises. Conversely, when most of the trials are incongruent, participants must engage in proactive control to reduce the influence of conflict-eliciting information. Interference effects tend to be smaller when most trials are incongruent because proactive control focuses attention on task goals (Braver, 2012; West & Bailey, 2012). To the extent that alcohol-related stimuli capture attention and interfere with ongoing task goals, manipulating the proportion of alcohol- and nonalcohol-related words should effectively vary the amount of conflict that LS individuals encounter in the alcohol Stroop task, and should affect their performance accordingly. This hypothesis was tested in the current study.

ERPs can be used to determine the extent to which reactive and proactive control processes are engaged during cognitive task performance. Specifically, two ERP components—the N2 and frontal slow wave (FSW)—are thought to index the engagement of reactive and proactive control, respectively. The N2 is a transient negativity over frontal and frontal-central scalp sites generally peaking 200–350 ms after stimulus onset and believed to reflect the conflict-monitoring function of the anterior cingulate cortex (ACC; see Larson, Clayson, & Clawson 2014; van Veen & Carter, 2002). The N2 is larger on incongruent relative to congruent trials (see Folstein & Van Petten, 2008), reflecting the ACC's signaling of conflict in the moment, believed to direct motor responses in a goal-consistent manner (Hoffstaedter et al., 2014). This in-the-moment adjustment is characteristic of reactive control (Braver, 2012). Previous research also suggests that the N2 is sensitive to probability, being larger when high-conflict trials are infrequent (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). Thus, the frequency of trial types (alcohol- and nonalcohol-related words) was manipulated across blocks in the current study. To the extent that alcohol-related words produce conflict for LS drinkers during the alcohol Stroop, the N2 should be most pronounced when such words are less frequent.

The FSW is a relatively low-frequency negative voltage deflection arising late in stimulus-locked ERP epochs over frontal scalp locations (West & Bailey, 2012), generally is larger following incongruent relative to congruent Stroop trials (Bailey, West, & Anderson, 2010; West, Bailey, Tiernan, Boonsuk, & Gilbert, 2012) and is thought to reflect activity in the lateral prefrontal cortex associated with conflict-related control adjustments (West & Bailey, 2012; West et al., 2012). The FSW is correlated with behavioral indices of control adjustment (Bailey et al., 2010; Bailey, Bartholow, Saults, & Lust, 2014) and is sensitive to manipulations of the proportion of high-conflict trials (West & Bailey, 2012). The sustained timing of the FSW and its sensitivity to changes in task difficulty (i.e., amount of control required to maintain performance) suggests it indexes engagement of proactive control.

The Current Study

LS and HS individuals performed an alcohol Stroop task while ERPs were recorded. The task included two trial blocks, a "mostly neutral" block in which neutral words were more frequent (75%) than alcohol words (25%), and a "mostly alcohol" block in which these frequencies were reversed. DMC theory (Braver, 2012; De Pisapia & Braver, 2006) posits that less frequent conflict leads to a reliance on reactive control (at the expense of proactive control) to respond to conflict as it arises, eliciting larger neural conflict responses (N2 amplitude) and more reaction-time (RT) interference (see also West & Bailey, 2012). Based on this idea, we predicted that LS participants (but not their HS counterparts) would experience larger N2 and greater RT interference from alcohol words (relative to neutral words) in the mostly neutral block compared to the mostly alcohol block. When conflict is more frequent, however, DMC theory predicts that resource-intensive proactive control will increase, which should reduce the extent to which high-conflict stimuli elicit interference and reactive control. To the extent LS individuals experience greater conflict overall when alcohol stimuli are more prevalent, their FSW amplitude should be larger and response accuracy should be higher in the mostly alcohol compared to the mostly neutral block. Alcohol words were not expected to elicit conflict for HS participants, and therefore no trial type or block effects were predicted for that group.

Method

Participants

University undergraduates completed the Alcohol Sensitivity Questionnaire (ASQ; Fleming, Bartholow, Hilgard, McCarthy, & Sher, 2016; O'Neill, Sher, & Bartholow, 2002) as part of a mass testing survey administered to over 2,000 Introductory Psychology students. Individuals whose responses represented the upper and lower quartiles of ASQ scores (stratified by sex) were invited to participate in a study on reaction time ability and brain activity.

Table 1. *vMeans (and SDs) for Alcohol Use and ASQ Score as a Function of Alcohol Sensitivity Group*

	Group		
Alcohol variables	LS	HS	Between-group differences
ASQ Score	7.36 (1.99)	5.24 (1.81)	$t(78) = -4.99$, $p < .0001$, $d = 1.13$
Q/F past 3 months	10.85 (9.40)	3.08 (3.89)	$t(78) = -4.83$, $p < .0001$, $d = 1.09$
Q/F past 30 days	10.71 (9.26)	2.74 (3.34)	$t(78) = -5.12$, $p < .0001$, $d = 1.16$

Note. ASQ = alcohol sensitivity questionnaire; Q/F = alcohol quantity/frequency, calculated as the number of drinking occasions per week multiplied by the typical number of drinks consumed per occasion; HS = high sensitivity; LS = low sensitivity.

Ninety-one individuals (ages 18–27; $M = 20$, $SD = 2$) completed the experiment in exchange for partial course credit or $30. Data from five HS and six LS individuals were excluded due to computer errors during testing ($n = 3$) or excessive artifact in the EEG (i.e., greater than 25% of trials exceeded the artifact rejection criteria of +/– 100 μV; $n = 8$). Therefore, analyses included data from 80 individuals (40 HS and 40 LS; 50% women).

Self-Report Measures

Typical alcohol use. Participants reported the average number of drinking occasions (e.g., Once; 2–3 times) and average number of drinks consumed per occasion in both the past 3 months and the past 30 days using items adapted from the National Institute on Alcohol Abuse and Alcoholism (NIAAA) Task Force recommendations (NIAAA, 2003). An alcohol quantity/frequency variable was created by multiplying the number of typical drinking occasions by the estimated number of drinks typically consumed per occasion (see Table 1).

Alcohol sensitivity. Self-reported sensitivity to the acute effects of alcohol was measured using the 15-item ASQ. This measure was developed as a way of assessing variability in sensitivity to a wider variety of alcohol effects than are queried in the Self-Report of the Effects of Alcohol (SRE) form (Schuckit et al., 1997), which focuses mainly on aversive effects associated with relatively large doses of alcohol (e.g., stumbling gait; passing out) and which requires respondents to recall effects of alcohol they often experienced many years ago (i.e., their first five drinking experiences). With the ASQ, respondents indicate whether or not they have ever experienced each of 15 effects from drinking alcohol (e.g., feeling more relaxed; feeling more talkative; feeling flirtatious; feeling nauseous; passing out), and for each effect endorsed indicate the minimum number of drinks they must consume in order to experience it (nine items, ostensibly associated with rewarding effects) or the maximum number of drinks they can consume without experiencing it (six items, ostensibly associated with punishing effects). For purposes of the current study, alcohol sensitivity scores were calculated by averaging the number of drinks reported for each item endorsed (i.e., collapsing across ostensibly rewarding and punishing effects).

Given evidence that patterns of missing data on alcohol survey responses (i.e., more "missingness" on more severe items) produce downwardly biased alcohol sensitivity estimates when traditional scoring methods are used, ASQ scores were calculated using a recently developed standardized person mean imputation (SPMI) approach (see Lee, Bartholow, McCarthy, & Sher, 2015). SPMI assumes that individuals' elevation relative to the mean should be similar across items; therefore, each item on the ASQ was converted into a z score before averaging across all nonmissing items to create a composite ASQ score. Internal consistency in the current sample was excellent ($\alpha = .92$). The mean number of items endorsed on the ASQ in this sample was 11.40.[1]

Construct validity of the ASQ has been demonstrated by research (Fleming et al., 2016) showing that scores on the ASQ predict self-reports of subjective alcohol effects during laboratory alcohol challenge as well as or better than scores on the SRE. Specifically, higher scores (indicating the need for more drinks to experience effects) were associated with increased feelings of stimulation (under ascending blood alcohol concentration) and decreased feelings of sedation, following a 0.80 g/kg dose of alcohol, generally consistent with predictions based in the modified Differentiator Model of alcoholism risk (see King, de Wit, McNamara, & Cao, 2011). Thus, for purposes of this research, higher ASQ scores (i.e., the LS group) are assumed to reflect lower sensitivity to alcohol's sedative effects and heightened sensitivity to alcohol's stimulating effects.

Alcohol Stroop Task

The alcohol Stroop task was modified from previous work (Cox et al., 1999; Field et al., 2007) to include a subset of words that were matched on usage frequency and to manipulate the proportion of word types across trial blocks. On each trial, participants were presented with one of four alcohol-related words (WINE, BEER, PUB, and BAR) or one of four neutral words (LAMP, KEY, SHOE, and BOX) in the center of a computer monitor, each presented in one of four colors (red, blue, green, yellow). Their task was to identify the color of the words as quickly as possible by pressing one of four response buttons. Alcohol and neutral words did not differ in length (alcohol: $M = 3.5$ letters, $SD = 0.58$; neutral: $M = 3.5$ letters, $SD = 0.57$; $t < 1$, $p = 0.99$) or log frequency (alcohol: $M = 10.4$, $SD = 0.86$; neutral: $M = 10.2$, $SD = 1.79$; $t < 1$, $p = 0.88$; Balota et al., 2007). Participants completed two blocks of 192 trials each. The *mostly neutral* block consisted of 144 neutral words and 48 alcohol words; the *mostly alcohol* block consisted of 144 alcohol words and 48 neutral words. Stimuli were presented in a random order within a block; block order was counterbalanced across participants. Stimuli remained on the screen until the participant responded, followed by a blank screen for 1,000 ms.

Electrophysiological Recording and ERP Measurement

EEG was recorded from 32 Ag/AgCl electrodes fixed in a stretch-lycra cap (Electro-Cap International, Eaton, OH) and placed

1. ASQ data initially were scored using traditional mean imputation (i.e., items not endorsed by an individual are ignored in determining her/his ASQ score), and participants were assigned to sensitivity groups on the basis of those scores. However, subsequent to participant selection for this study, the improved SPMI scoring method was developed (Lee et al., 2015), and this method was retroactively applied to the ASQ data in the current sample. Critically, in the current dataset both approaches yielded comparable ASQ scores (traditional approach: HS $M = 7.09$, $SD = 2.13$; LS $M = 4.22$, $SD = 1.98$), and the significance of reported group differences was comparable across the two scoring methods.

according to the standard 10–10 system (American Electroencephalographic Society, 1994). Electrodes were referenced online to the right mastoid; an average mastoid reference was calculated offline. A ground electrode was placed along the frontal midline (Fpz). Signals were amplified using a Neuroscan Synamps2 amplifier (Compumedics, Charlotte, NC) and filtered online at .01–40 Hz at a sampling rate of 1,000 Hz. Impedance was kept below 5 KΩ at all channels. Ocular artifacts were corrected from the EEG signal offline using ICA in the EEGLAB toolkit (Delorme & Makeig, 2004). Trials containing voltage deflections of +/– 100 μV were discarded (< 2% of all trials). EEG data were segmented into epochs of −200 to 1,000 ms of poststimulus activity (baseline: −200 to 0 ms) for construction of stimulus-locked ERPs. Separate averages (low-pass filtered at 20 Hz) were created for each stimulus condition at each electrode, separately for the LS and HS groups.

Procedure

Upon arrival at the laboratory, participants provided informed consent and completed the alcohol use measure. The electrode cap was then applied and participants completed the alcohol Stroop task.[2] Finally, the electrodes were removed and the participants were debriefed, compensated, and dismissed.

Analytic Approach

To properly account for the mixed factorial nature of the study design and apportion individual-level variance appropriately, primary analyses were carried out with multilevel modeling (MLM) using SAS proc mixed (SAS Institute, 2008).[3] MLM has several advantages over traditional repeated-measures analysis of variance (ANOVA) for analyzing both psychophysiological data (see Kristjansson, Kircher, & Webb, 2007; Page-Gould, in press) and proportion data, both of which frequently violate the assumption of sphericity (i.e., that the variances of differences between factor levels are equal). This assumption is relaxed in MLM, precluding the need to apply an angular transform to the accuracy data in order to normalize residual variance across conditions and minimize ceiling effects. Other advantages of MLM include the ability to simultaneously estimate both within-participant and between-participants effects (see Bryk & Raudenbush, 1992), the ability to specify separate error terms at each level of nesting, and robustness to missing observations, which in repeated-measures ANOVA leads to rejection of the individual's entire record (i.e., list-wise deletion).

Here, data from each dependent variable were subjected to separate 2 (Group: HS, LS) x 2 (Block: mostly alcohol, mostly neutral) x 2 (Trial: alcohol, neutral) mixed models with random intercepts specified for each participant; an additional two-level factor for electrode location (Fz, FCz) was included in the models examining the N2 and FSW data. RTs were limited to responses made between 100–2,000 ms after target onset, to reduce the influence of a few extremely slow responses (< 1% of trials) and to eliminate fast "guessing" responses. Initial inspection and analysis of the ERPs indicated that N2 amplitude was maximal between 300–400 ms poststimulus over the midline frontal and frontal-central electrodes (Fz and FCz). Amplitude of the FSW was maximal over the same region of the scalp between 800 to 1,000 ms poststimulus. Thus, these components were scored as the mean voltage within those time windows at electrodes Fz and FCz.

Table 2. *Mean Accuracy and RT (*ms*) as a Function of Group, Block, and Trial Type*

		Accuracy		RT	
		Block			
Group	Trial	Mostly alcohol	Mostly neutral	Mostly alcohol	Mostly neutral
LS					
	Alcohol	.953	.961	735	756
		0.04	*0.03*	*103*	*110*
	Neutral	.959	.957	743	740
		0.03	*0.04*	*108*	*101*
HS					
	Alcohol	.962	.956	754	750
		0.02	*0.03*	*99*	*90*
	Neutral	.958	.959	755	735
		0.03	*0.03*	*102*	*85*

Note. Italicized numbers are standard deviations.

Results

Behavioral Data

RT. The Block x Trial interaction was significant, $F(1, 234) = 4.60$, $p = 0.033$, $R^2 = .019$. RTs were slower for alcohol ($M = 753$ ms, $SD = 100$) than neutral words ($M = 738$ ms, $SD = 93$) in the mostly neutral block, $t(234) = 2.41$, $p = 0.017$, but did not differ significantly for alcohol ($M = 745$ ms, $SD = 101$) and neutral words ($M = 749$ ms, $SD = 105$) in the mostly alcohol block, $t < 1$, $p = 0.534$. The Group x Block interaction was also significant, $F(1, 234) = 5.23$, $p = 0.023$, $R^2 = .022$. Examination of the means suggests faster RTs in the mostly alcohol compared to the mostly neutral block ($\Delta = -9$ ms) among LS participants but slower responses in the mostly alcohol compared to the mostly neutral block ($\Delta = +12$ ms) among HS participants; however, neither of these block effects was significant, $ts(234) < 1.85$, $ps > .066$. The Group x Block x Trial interaction was not significant ($F < 1$).

Our hypotheses specify a pattern in the RT data that is only partially correlated with this higher-order interaction and is more appropriately tested with a set of a priori contrasts (see Rosnow & Rosenthal, 1995). Specifically, we predicted that LS individuals would experience greater RT interference from alcohol words (relative to neutral words) in the mostly neutral block than in the mostly alcohol block, whereas no such block difference was anticipated for the HS participants. To test the magnitude of this hypothesized pattern, we computed a set of focused contrasts in which the trial type effect was given larger weights in the mostly neutral block (−2 and +2 for alcohol and neutral words, respectively) than in the mostly alcohol block (+1 and −1, respectively) for LS participants, but equivalent weighting was used across blocks for HS participants. This contrast was significant, $t(234) = 2.28$, $p = .023$, $d = .51$, supporting our prediction.

Accuracy. The Group x Block x Trial interaction was significant, $F(1, 234) = 4.20$, $p = 0.042$, $R^2 = .018$ (see Table 2). To understand this complex interaction, separate Block x Trial MLMs were computed on the accuracy scores within the two groups. Neither of these lower-order interactions was significant, $Fs(1, 117) = 2.57$

2. Participants also completed a color-word Stroop task following the alcohol Stroop, but those data will not be reported in this manuscript. We have otherwise reported all measures, conditions, data exclusions, and sample sizes.

3. Versions of the analyses using more traditional repeated-measures analyses of variance are reported in the Supporting Information.

Table 3. *Mean Amplitude (µV) of the N2 and FSW as a Function of Group, Block, and Trial Type*

		N2		FSW	
		Block			
Group	Trial	Mostly alcohol	Mostly neutral	Mostly alcohol	Mostly neutral
LS					
	Alcohol	1.12	0.42	0.02	0.45
		3.89	*3.99*	*1.96*	*2.38*
	Neutral	1.25	1.25	0.28	0.33
		4.1	*4.17*	*2.87*	*1.98*
HS					
	Alcohol	0.64	0.89	0.11	−0.09
		3.29	*3.98*	*2.12*	*2.48*
	Neutral	0.19	0.94	0.14	0.09
		3.93	*3.58*	*2.11*	*2.19*

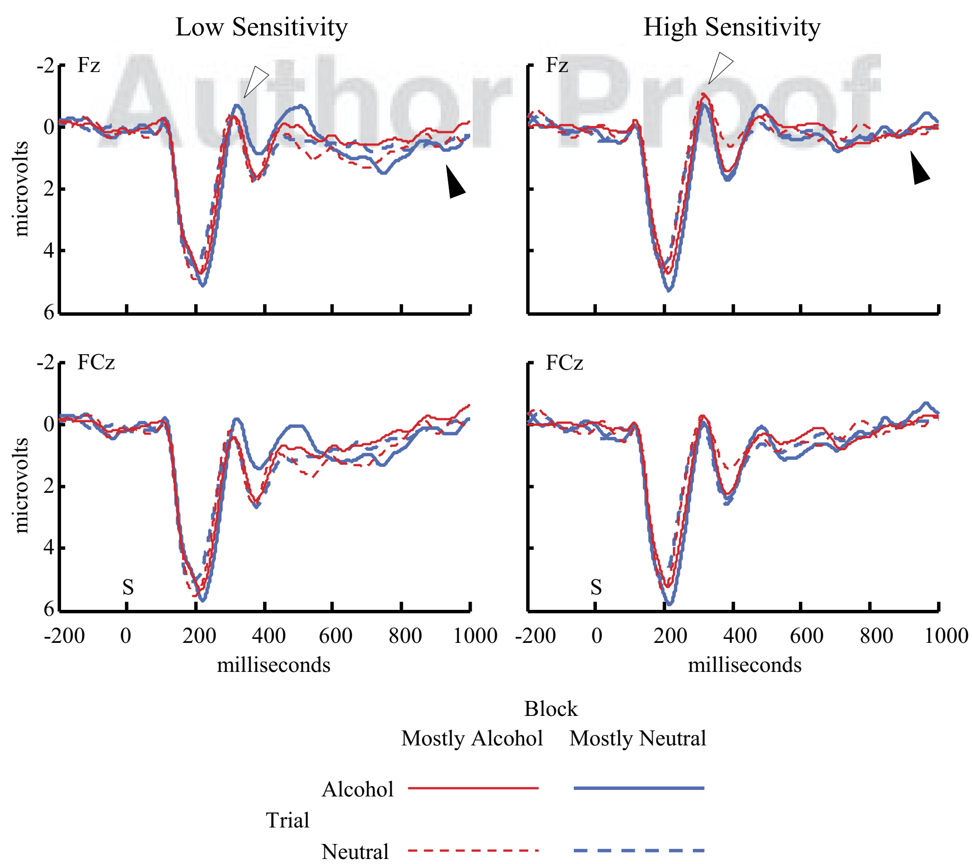
Note. Italicized numbers are standard deviations.

and 1.65 for LS and HS, respectively, $ps > .11$. However, inspection of the means in Table 2 suggests the patterns of trial type effects across the blocks were essentially opposite for LS and HS participants. Of primary interest for our hypotheses was whether LS individuals' color-naming of alcohol words was more accurate in the mostly alcohol compared to the mostly neutral block. Contrary to this prediction, LS participants were actually more accurate on alcohol word trials in the mostly neutral block, $t(117) = -2.16$, $p = .033$. Thus, this prediction was not supported.

ERP Markers of Reactive and Proactive Control

N2 amplitude. Analysis of mean N2 amplitude (see Table 3 and Figure 1) revealed a number of significant interactions. First, the Block x Trial interaction, $F(1, 554) = 7.33$, $p = 0.007$, $R^2 = .013$, indicated that N2 amplitude was greater (more negative) for alcohol ($M = .66$ µV, $SD = 3.97$) than for neutral words ($M = 1.10$ µV, $SD = 3.86$) in the mostly neutral block, $t(554) = 2.79$, $p = 0.005$, but did not differ significantly for alcohol ($M = .88$ µV, $SD = 3.59$) and neutral words ($M = .72$ µV, $SD = 4.03$) in the mostly alcohol block $t(554) = -1.04$, $p = .297$. The Group x Trial interaction was also significant, $F(1, 554) = 9.28$, $p = 0.002$, $R^2 = .016$. For HS individuals, N2 amplitude did not differ significantly for alcohol ($M = .77$ µV, $SD = 3.50$) and neutral words ($M = .56$ µV, $SD = 3.63$), $F < 1$, $p = 0.364$. For LS individuals, however, N2 amplitude was significantly greater (more negative) for alcohol ($M = .77$ µV, $SD = 3.84$) than neutral words ($M = 1.25$ µV, $SD = 4.01$), $t(554) = -3.05$, $p = 0.002$. Finally, the Group x Block interaction was significant, $F(1, 554) = 14.57$, $p < 0.001$, $R^2 = .026$. For HS individuals, N2 amplitude was larger (more negative) in the mostly alcohol ($M = .42$ µV, $SD = 3.53$) compared to the mostly neutral block ($M = .92$ µV, $SD = 3.65$), $t(277) = 3.12$, $p = 0.002$; in contrast, for LS individuals N2 amplitude was larger in the mostly neutral block ($M = .84$ µV, $SD = 3.99$) than in the mostly alcohol block ($M = 1.18$ µV, $SD = 3.91$), $F(1, 277) = 5.13$, $p = 0.024$.

Our primary prediction for the N2 amplitude data was that LS participants would experience larger N2 conflict effects (alcohol > neutral words) in the mostly neutral block compared to the



COLOR

Figure 1. Stimulus-locked ERP waveforms for LS (left-hand column) and HS (right-hand column) individuals, illustrating the N2 (white arrow) and FSW (black arrow) components. "S" (time zero) indicates stimulus array onset.

mostly alcohol block; no such block effect was predicted for the HS group. These predictions were tested with a set of a priori contrasts in which the trial type effect was given larger weights in the mostly neutral block (−2 and +2 for alcohol and neutral words, respectively) than in the mostly alcohol block (+1 and −1, respectively) for LS participants, but equivalent weighting was used across blocks for HS participants. This contrast was significant, $t(554) = 3.45$, $p < .001$, $d = .989$, supporting our prediction.

Although not predicted, inspection of the means in Table 3 suggests HS participants experienced larger N2 effects to neutral words in the mostly alcohol block than in the mostly neutral block, whereas alcohol words seemed to elicit equivalent N2 amplitudes in both blocks. In theory, this could occur if neutral words (especially when infrequent) are more salient than alcohol words to HS individuals. To test the magnitude of this apparent difference, we constructed a post hoc contrast specifying larger weights for neutral words across blocks (−2 and +2, respectively) than for alcohol words (+1 and −1). This contrast was significant, $t(554) = 2.53$, $p = .012$.

FSW amplitude. The analysis of FSW amplitudes (see Table 3 and Figure 1) revealed no significant main effects or interactions, Fs$(1, 554) < 2.59$, ps > 0.108. However, the pattern of means in Table 3 is generally consistent with the prediction that, among LS participants, the FSW would be larger (less positive) in the mostly alcohol block than in the mostly neutral block. We tested this prediction using a set of a priori contrasts in which larger weights were assigned to the alcohol block (−2 and +2) than the neutral block (+1 and −1) for the LS group but equal weighting of block blocks for the HS group. This contrast was marginal, $t(554) = 1.68$, $p = .093$.

Testing the reactive-proactive dissociation. DMC theory posits a dissociation between reactive and proactive forms of control, which should vary according to the likelihood of conflict (De Pisapia & Braver, 2006). The pattern of means in Table 3 appears to suggest differential sensitivity among LS participants of the N2 (reactive control) and FSW (proactive control) to alcohol words as a function of their relative frequency: whereas the N2 was largest to alcohol words in the mostly neutral block, the FSW was largest to alcohol words in the mostly alcohol block. To test whether this apparent dissociation was significant, we applied a set of contrasts to the alcohol word responses across blocks, differentially weighting the N2 (+2 and −2 for mostly alcohol and mostly neutral, respectively) and FSW (−2 and +2, respectively) for LS participants, and assigning equivalent weights across blocks and components for the HS participants. This contrast was significant, $t(554) = 2.26$, $p = .024$, supporting the idea that the probability of encountering alcohol-related stimuli differentially engages reactive and proactive control processes in LS drinkers.

Associating Neural and Behavioral Indices of Control

Although not specifically predicted, we explored possible associations between our behavioral and ERP measures using a series of bivariate correlations calculated in conditions of theoretical interest. First, our primary prediction that alcohol words would elicit conflict among the LS participants suggests an association between the N2 amplitude and RT measures for alcohol words. This correlation was significant for trials in the mostly neutral block (when conflict was strongest), $r = -.320$, $p = .044$, but not for trials in the mostly alcohol block (when conflict was less pronounced), $r = -.167$, $p = .303$. The pattern in the mostly neutral block suggests that individuals who experienced more conflict (larger [less positive] N2 amplitude) for alcohol words also tended to respond more slowly to those words. Analogous correlations between N2 and RT measures on alcohol word trials among HS participants were small and nonsignificant (rs $< .09$, ps $> .56$).

The other prediction suggesting an association between behavioral and neural measures was that LS individuals would be more accurate in color-naming alcohol words in the mostly alcohol block than in the mostly neutral block, and that this would be accompanied by larger FSW in the mostly alcohol than in the mostly neutral block. As already reported, the hypothesis of greater accuracy for alcohol words in the mostly alcohol block was not supported, suggesting that LS participants had difficulty implementing proactive control in the context of frequent high-conflict stimuli. Examination of the correlation between accuracy and FSW amplitude in this condition showed a nonsignificant but modest positive association, $r = .258$, $p = .108$. The positive sign on this correlation indicates that increased accuracy was associated with smaller (more positive) FSW amplitude, contrary to what might be expected.

Finally, we examined the associations between the N2 and FSW across conditions for both groups. In essence, these associations can be said to reflect the degree of similarity in the sensitivity of the reactive (N2) and proactive (FSW) cognitive control systems within each group. Interestingly, whereas the two neural measures were correlated in all conditions among HS participants, rs $= .406$ to $.559$, ps $\leq .009$, they did not correlate in any condition among LS participants, rs $= .024$ to $.095$, ps $\geq .557$.

Discussion

On the basis of prior research suggesting that alcohol-related cues capture attention and distract at-risk drinkers from the pursuit of larger goals (Cox et al., 1999; Fleming & Bartholow, 2014; Shin et al., 2010), it was predicted here that for LS participants, the meaning of alcohol-related words would conflict with the task of naming their color. It was further predicted on the basis of recent theorizing (Braver, 2012) that the relative frequency of alcohol-related words would determine the conflict processes they engendered and hence, the control strategies LS individuals would employ to deal with that conflict. Consistent with these predictions, among LS (but not HS) participants RTs were slower and N2 amplitudes greater for alcohol trials than for neutral trials in the mostly neutral block, relative to the mostly alcohol block. This pattern suggests that reactive control processes were recruited in response to the rather unpredictable conflict alcohol words created in the mostly neutral block. However, the current data provide only mixed support for the idea that alcohol stimuli encountered under conditions of more frequent conflict (i.e., the mostly alcohol block) recruit proactive control in LS drinkers. On the one hand, LS participants experienced less RT interference from alcohol (relative to neutral) words in the mostly alcohol block (−8 ms) compared to the mostly neutral block (16 ms), and there was also no conflict-related N2 amplitude effect in the mostly alcohol block, consistent with the DMC-based prediction that proactive control dominates when conflict is more frequent (Braver, 2012; De Pisapia & Braver, 2006), which reduces the experience of conflict "in the moment." The fact that the FSW elicited on alcohol word trials showed essentially the opposite pattern—larger in the mostly alcohol block compared to the mostly neutral block—relative to the N2 also supports this idea and is consistent with previous work showing a double dissociation among neural responses linked to reactive and proactive control across conditions of low- versus high-frequency conflict (West & Bailey, 2012).

On the other hand, LS participants were less accurate in identifying the color of alcohol words when they were more frequent, a pattern inconsistent with what both theory (Braver, 2012) and previous research (West & Bailey, 2012) have associated with the influence of proactive control. Thus, more work is needed to determine the extent to which LS individuals can engage proactive control in situations saturated with alcohol cues.

At first glance, it can seem somewhat puzzling that the larger RT interference effects reported under conditions of low-probability conflict, both here and in previous research (e.g., Bugg & Hutchison, 2013; De Pisapia & Braver, 2006; West & Bailey, 2012), are associated with utilization of a form of control given that RT interference often has been interpreted as evidence of failure (or at least difficulty) in overcoming some stimulus-related conflict. However, considering the current behavioral and ERP data together provides a context in which to understand this interference effect as reflecting control implementation. For instance, LS participants' responses to alcohol words in the mostly neutral block were both slower and more accurate, suggesting a more careful (as opposed to quick and impulsive) response strategy on those trials. When considered alongside the enhanced N2 experienced by LS participants on those trials, this pattern points to a process by which conflict detection (N2 amplitude) prompted a more deliberative activation of motor responses to ensure accurate color-naming performance, consistent with numerous neurocognitive control models (e.g., Botvinick & Cohen, 2014; Carter & van Veen, 2007) and the putative role of ACC in guiding goal-directed motor responses (Hoffstaedter et al., 2014).

In recent years a number of studies have reported findings consistent with the idea that alcohol-related stimuli are particularly motivationally salient to LS drinkers (Bartholow, Henry, & Lust, 2007; Bartholow et al., 2010), leading such stimuli to spontaneously capture their attention (Shin et al., 2010) and interfere with self-regulatory goal pursuit (Fleming & Bartholow, 2014). The current study extends this previous work in three important ways. First, whereas previous research has shown that LS individuals are more reactive than their HS peers to visual alcohol cues, the current work indicates that even abstract, verbal stimuli associated with alcohol are salient to LS drinkers, producing conflict that interferes with task goals. Second and more broadly, whereas previous work (Fleming & Bartholow, 2014) showed that alcohol-related cues exacerbate the experience of conflict for LS drinkers in a situation that expressly called for conflict resolution (i.e., withholding responses to infrequent no-go targets), the current findings indicate that alcohol-related cues can cause conflict even in contexts where cognitive/inhibitory control is not expressly called for. One potential implication is that for LS individuals, environments rich in alcohol-related cues might pose extraordinary challenges for maintaining goal pursuit and self-regulatory control. Finally, by specifically linking attention bias, cue-elicited response conflict and performance in the alcohol Stroop task to neural and behavioral markers of reactive and proactive cognitive control (Braver, 2012), the current research provides a theoretically rich context in which to understand problematic cue reactivity responses in LS drinkers.

A few limitations of the current study should be mentioned. First, the alcohol sensitivity groups were derived from scores on the ASQ, and although the construct validity of this measure recently has been demonstrated (see Fleming et al., 2016), such self-report measures only partially capture the full scope of differences in alcohol sensitivity. Additionally, despite controlling for the frequency of stimulus words used in the alcohol Stroop in this study, it could be that LS and HS drinkers have different exposure histories with alcohol words that could influence their reactivity to them. This seems unlikely, however, given that all participants were selected from a university campus where alcohol is ubiquitous and where even nondrinkers are routinely exposed to alcohol cues.

Another limitation of this and all such studies is that the individual differences design limits our ability to draw causal inferences concerning alcohol sensitivity and cognitive control. Although considerable evidence points to genetic factors in accounting for interindividual variability in alcohol sensitivity (e.g., Joslyn, Ravindranathan, Brush, Schuckit, & White, 2010; Viken, Rose, Morzorati, Christian, & Li, 2003), it could be that both cue-reactivity differences and alcohol sensitivity levels are rooted in other causes, such as differences in the frequency or quantity of alcohol consumption, which also influence conflict and cognitive control. Indeed, given that ASQ scores and alcohol consumption (quantity-frequency composite) generally correlate modestly ($r = .32$, $p = .004$ in the current dataset; see also Bartholow et al., 2007, 2010; Fleming & Bartholow, 2014), it could be that the effects associated with alcohol sensitivity reported here are simply masking effects associated with consumption levels. To examine this possibility, we conducted a set of ancillary analyses in which the sample was divided into relatively heavy-drinking and light-drinking groups on the basis of self-reported alcohol use in the past 30 days (see Table 1). These analyses produced no significant interactions involving the group variable.[4] Although this pattern supports the contention that alcohol sensitivity and consumption are not identical constructs with overlapping associations to other processes (Bartholow et al., 2007; Schuckit et al., 2011), distinguishing their relative contributions to cognitive control and cue-reactivity remains an important issue for the field.

In conclusion, the current study provides further support for the idea that alcohol-related cues produce conflict that can interfere with LS individuals' goal pursuit. Moreover, further investigating this and related questions within the DMC model framework (Braver, 2012), from which hypotheses regarding specific modes of control operating under varying environmental circumstances can be tested, may provide an opportunity to increase understanding of cognitive factors that convey greater risk for alcohol abuse and related problems (Gierski et al., 2013). It would be useful for future research to continue to examine potential trade-offs between

4. Some might assume that a better approach to addressing this concern would be to include the alcohol quantity-frequency variable as a covariate in the primary analyses. However, given the association between alcohol consumption and sensitivity, alcohol consumption should not be considered an independent, confounding factor in sensitivity levels, and therefore this approach would be inappropriate on both conceptual and empirical grounds (see Miller & Chapman, 2001). Paraphrasing Miller and Chapman, statistical methods cannot remove the "effect" of one variable from another variable if the two represent conceptually overlapping constructs.

reactive and proactive forms of control, their associations with levels of alcohol sensitivity, and their links to alcohol-related negative consequences, which could suggest avenues for intervention with at-risk drinkers.

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Appendix S1.

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