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Alcohol-Induced Changes in Conflict Monitoring and Error Detection as Predictors of Alcohol Use in Late Adolescence

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Adolescence is a vulnerable period for the development of substance use and related problems. Understanding how exposure to drugs influences the adolescent brain could reveal mechanisms underlying risk for addiction later in life. In the current study, 87 adolescents (16–20-year olds; the local legal drinking age was16, allowing the inclusion of younger subjects than usually possible) underwent EEG measurements during a Go/No-Go task with and without alcohol cues; after placebo and a low dose of alcohol (0.45 g/kg). Conflict monitoring and error detection processes were investigated with the N2 and the error-related negativity (ERN) ERP components. Participants were followed-up after 6 months to assess changes in alcohol use. The NoGo-N2 was larger for alcohol cues and acute alcohol decreased the amplitude of the NoGo-N2 for alcohol cues. ERN amplitude was blunted for alcohol cues. Acute alcohol decreased the amplitude of the ERN, specifically for control cues. Furthermore, the differences in ERN for alcohol cues between the placebo and alcohol conditions predicted alcohol use 6 months later: subjects who showed stronger blunting of the ERN after acute alcohol were more likely to return to more moderate drinking patterns. These results suggest that cues signalling reward opportunities might activate a go-response mode and larger N2 (detection of increased conflict) for these cues might be necessary for inhibition. The ERN results suggest a deficiency in the monitoring system for alcohol cues. Finally, a lack of alcohol-induced deterioration of error monitoring for cues with high salience might be a vulnerability factor for alcohol abuse in adolescents.
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INTRODUCTION

Dual process models explain addiction as the result of an imbalance between an appetitive and a regulatory system (Stacy *et al*, 2004; Deutsch *et al*, 2006; Wiers *et al*, 2007; but see Gladwin *et al*, 2011). Accordingly, poor response inhibition predicts drinking problems in high-risk children (Nigg *et al*, 2004; 2006) and a transition to problem drinking in adolescents (Norman *et al*, 2011). This may be related to the more general finding that adolescent cognitive performance is relatively weak in 'hot' (emotionally or motivationally salient) *vs* 'cold' contexts (Crone and Dahl, 2012; Grose-Fifer *et al*, 2013; Gladwin and Figner, 2014). Relatively weak performance of adolescents in an affective context has been tentatively related to a delay in the development of neural system needed for behavioural regulation, relative to the development of emotional-motivational system (Jentsch and Taylor, 1999; Casey and Jones, 2010). The anterior cingulate cortex (ACC) is a key structure involved in response inhibition and monitoring of response conflicts (co-activation of competing actions) (Yeung *et al*, 2004; Bekker *et al*, 2005). Given its rich connections to the prefrontal cortex and limbic structures, ACC-regulated processes are likely to be affected by the interplay between control and motivation. Neural activity associated with conflict monitoring has been associated with alcohol use severity (Claus *et al*, 2013) and density of family history of alcoholism (Fein and Chang, 2008). Thus, inhibition and conflict monitoring in an affective context are likely to play a role in the vulnerability for addiction in adolescents.

The acute disinhibiting effects of alcohol may lead to escalation of alcohol use (review: Field *et al*, 2010). This may be due to an increase in appetitive motivation towards drug cues and/or a decrease in regulatory cognitive control (Ridderinkhof *et al*, 2002; Duka and Townshend, 2004; Hernández and Vogel-Sprott, 2010; Adams *et al*, 2013). Acute alcohol effects may mimic long-term effects and could thus predict escalation (Wiers *et al*, 2007). Note that both relatively strong direct appetitive effects and relatively weak later responses to alcohol in terms of negative effects (eg, on balance) have been related to individual differences in the risk for later addiction (Newlin and Thomson, 1990; Schuckit *et al*, 2000).

The electroencephalogram (EEG) can be used to further study conflict monitoring, response inhibition, and error detection. According to the conflict monitoring theory, the

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ACC monitors conflict that arises because of co-activation of competing actions to deploy additional cognitive resources. The ACC generates the N2 event-related potential (ERP) component, when it detects *pre-response conflict* on correctly inhibited trials (Van Veen and Carter, 2002). Another ERP component, the error-related negativity (ERN), is thought to be related to *error detection* and generated by the ACC when a correct response is activated after an error, resulting in *post-response conflict*. Evidence supports the involvement of both conflict monitoring and response inhibition in N2 generation: the N2 was enhanced for low-frequency stimuli regardless whether a response must be generated or suppressed (Nieuwenhuis *et al*, 2003) and for NoGo stimuli when the frequency of required Go/NoGo responses was equal, also the response conflict (Lavric *et al*, 2004).

In adults, effects of alcohol on the ERP suggest impaired error detection but intact conflict monitoring (Ridderinkhof *et al*, 2002; Easdon *et al*, 2005; Bartholow *et al*, 2012). In a simulation study, Yeung and Cohen (2006) showed that the ERN and the N2 could be sensitive to relevant and irrelevant stimulus information, respectively. Further, the ERN is modulated by affective cues (Larson *et al*, 2006), which may be related to the disruption of inhibition in an affective context (Noël *et al*, 2007; Grose-Fifer *et al*, 2013). To our knowledge, acute alcohol effects on conflict monitoring in the context of motivationally relevant alcohol cues has not been investigated yet in drinking adolescents.

The current study focused on two questions: (i) Are response inhibition and conflict monitoring processes influenced by acute alcohol in adolescents and is this moderated by the motivational relevance of the cues? (ii) Do brain potentials, moderated by alcohol, predict future alcohol use in adolescents? To this aim, a Go/NoGo task including both alcohol and soft drink stimuli was used. We expected the ERN and the N2 to be dampened after acute alcohol and for alcohol *vs* soft drink cues. Participants' change in alcohol use was assessed after 6 months. Differences across dose conditions were expected to predict short-term prospective escalation of alcohol use.

MATERIALS AND METHODS

Participants

Ninety-seven adolescents were recruited from local high schools via advertisements. Participants were required to be minimally 16 years old (minimum drinking age in Netherlands at the time of the study), with a minimum weight of 50 kg and to have had at least one full drink in their lifetime (see Supplementary Materials for exclusion criteria). Prior to the experiment, a written informed consent was obtained from all participants and from parents of participants under the age of 18. Ten subjects' data were excluded for the following reasons: three because of positive drug test for THC, one because of a drop-out in the second session, four because of equipment failure, one because of incorrect beverage administration, and one because of an extreme number of omission trials. The analysis was conducted with the remaining 87 subjects (33 males, mean age = 17.6 years, range = 16–20 years).

Alcohol Administration and Procedure

The study consisted of two sessions on two different days. On each session, either a placebo or an alcoholic drink (0.45 ml/kg) was administered. Beverages were divided into three equal portions. Two of the drinks were served prior to commencing the tasks and the last drink was administered as a booster drink halfway through the session (for details on the alcohol administration see Supplementary Materials). Upon arrival in the lab, subjects filled out demographics, questionnaires related to personality and drinking habits. At the start of each session, subjects completed the *Desire for Alcohol Questionnaire* (DAQ, Love *et al*, 1998) and the *Positive and Negative Affect Scale* (PANAS, Watson *et al*, 1988) to control for current mood and craving. Current alcohol use and problems were assessed with the *Alcohol Use Disorder Identification Test* (AUDIT, Saunders *et al*, 1993; we used both the standard past year version and a version about the past 3 months), the Ruthers Alcohol Problem Index (RAPI, White and Labouvie, 1989), and an adjusted version of the Timeline Followback method developed by Sobell and Sobell, (1992) as reported in Wiers *et al* (1997). Drug use behaviour was assessed with an 11-item rating scale (Graham *et al*, 1984). To assess drinking frequency separately for weekdays and weekends, subjects filled out three additional questions. This additional set included questions on the frequency and the quantity of drinking in the last 3 months and lifetime binge drinking frequency (see Supplementary Materials). The session started with an unrelated task, followed by beverage administration. Approximately 10 min after beverage administration, subjects also performed three unrelated tasks (see Supplementary Materials). Order of the tasks was counterbalanced across subjects, but was kept the same across sessions for each subject. Breath alcohol concentration (BrAC) was collected 5 min after the first two drinks, before and after the booster drink, and at the end of the experiment by using the Lion alcolmeter SD-400 (Lion Laboratories Limited, South Glamorgan, Wales). Participants filled out the *Brief Biphasic Alcohol Effects Scale* (B-BAES, Rueger *et al*, 2009) each time a breath sample was taken, except before the booster drink.

The sessions were carried out at least 48 h and maximally 1 week apart. Sessions started between 12 : 00 and 6 : 00 PM. Each session took approximately two and a half hours, including breaks and the application of electrodes. Six months after the baseline assessment, participants were contacted via email for an online assessment on recent alcohol and drug use. During the follow-up assessment, subjects filled out the same alcohol-related scales as during pre-test. The study was approved by the local ethical committee.

Go/NoGo Task

Subjects were presented with pictures of beverages in a bottle or in a glass. The task consisted of blocks with sets of either alcohol or soft drink pictures. In the alcohol blocks, the stimuli were alcohol-related pictures (eg, beer, wine), and in the neutral blocks, the stimuli were pictures of soft drinks (eg, cola, sprite). In the Go trials, a right button response was required for the pictures of a beverage in a

bottle (as quick as possible while maintaining accurate). In the NoGo trials, when the picture of a beverage in a glass was presented, subjects were required to withhold their responses. Four pictures were used in each block type, each consisting of three go stimuli and one no-go stimulus (eg, beer, Figure 1). Each stimulus was presented with equal frequency, leading to 25% no-go and 75% go trials (90 no-go and 270 go trials per block). Pictures with and without alcohol contents were matched for perceptual characteristics (ie, colour, shape etc.).

The task started either with the alcohol or the neutral block, counterbalanced across participants. After12 practice trials, the task consisted of 10 assessment blocks, with neutral and alcohol blocks alternating. Each stimulus was presented for 200 ms, followed by 800 ms and 1000 ms of ITI for go and no-go trials, respectively. To study error-related EEG activity, an adequate amount of commission errors were required, therefore an adaptive procedure was used. After each block, subjects' overall commission errors and correct responses in the no-go trials were calculated. When the ratio between commission errors/correct no-go responses was smaller or larger than 50/50, the next block started with a feedback encouraging, respectively, to 'speed up' or 'slow down' the response. If the ratio was equal, subjects received no feedback. To control for the effect of picture familiarity across sessions, two sets of pictures with and without alcohol contents were matched, and each stimulus set was randomly assigned to a session.

EEG Recording and Data Analysis

Electrophysiological data were recorded from the scalp using an Active-Two amplifier (Biosemi, Amsterdam, The Netherlands) from 32-scalp sites. Electrodes were placed at the standard positions of the 10–20 international system. Two electrodes were placed at the outer canthi of the eyes to measure horizontal eye movements. Two electrodes were placed at below and above the left eye to measure vertical eye movements. EEG was recorded at 2048 Hz sampling rate. The distance between the screen and the subject was kept 75 cm.

EEG analysis was conducted using Brain Vision Analyzer (version 2.0, Brain Products GmbH, Munich, Germany). Data were down-sampled to 250 Hz, re-referenced offline to the average of scalp electrodes, low pass filtered at 20 Hz, and high pass filtered at 0.1 Hz. Ocular correction was applied using the algorithm of Gratton *et al*, (1983). Stimulus and response-locked epochs ranged from -200 to 1000 ms and from -300 to 800 ms, respectively. Trials were considered artifacts when the difference between consecutive data points was larger than 50 mV and the difference between the lowest and the highest voltage within a segment was higher than 150 mV. Epochs with an amplitude exceeding ± 100 mV were excluded. The mean 200 ms pre-stimulus and pre-response period was used as baseline. After baseline correction, average stimulus-locked ERPs were calculated for artifact-free trials at each scalp location for trials with correct go, correct no-go, and commission responses separately. Average response-locked ERPs were created for trials with commission error responses only (for details on ERP quantification and subject/trial exclusion procedure, see Supplementary Materials).

Data Preparation and Statistical Analysis

For behavioral performance, mean RTs for correct go and commission error responses, average hit rates (trials with correct go response/trials with correct go plus omission responses), and false alarm rates (trials with commission

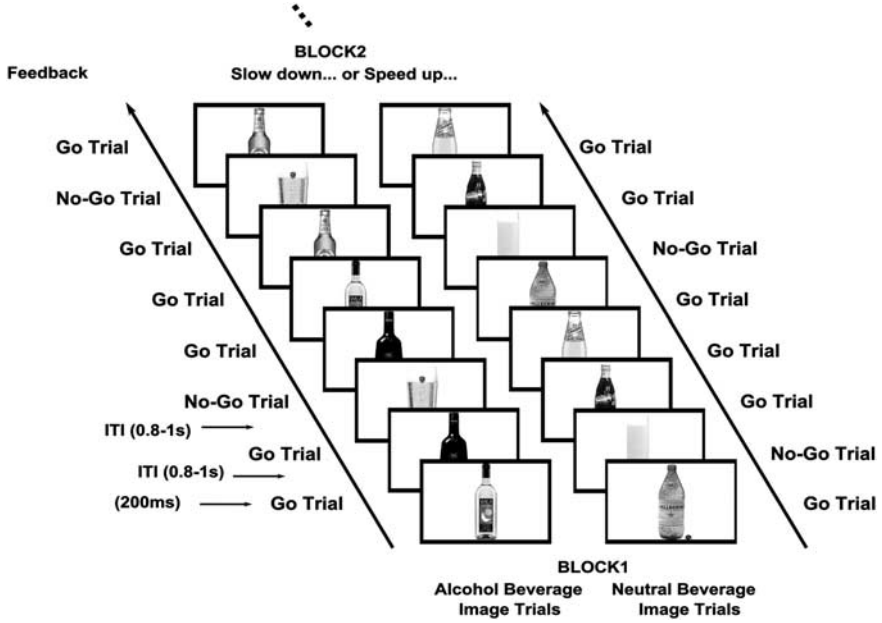

Figure 1 Schematic representation of the alcohol-related Go/NoGo Task. Subjects were presented with pictures of beverages in a bottle or in a glass. The task consisted of blocks with sets of either alcohol or soft drink pictures. In the Go trials, a right button response was required for the pictures of a beverage in a bottle. In the NoGo trials, when the picture of a beverage in a glass was presented, subjects were required to withhold their responses. The task consisted of 10 blocks, with neutral and alcohol blocks alternating. Each stimulus was presented for 200 ms, followed by 800 ms and 1000 ms of ITI for go and no-go trials, respectively.

response/trials with commission plus correct no-go responses) were calculated separately for the blocks with neutral and alcohol stimulus set in each condition.

All analyses were conducted using a repeated measures analysis of variance. The PANAS and DAQ scores were analyzed with *Dose* (Placebo, Alcohol) as a within-subject factor. The Stimulation and Sedation subscales of B-BAES scores were separately analyzed with *Dose* (Placebo, Alcohol), and *Time* (pre-task and post-task) as within-subject factors. The BrAC were subjected to a repeated measures analysis of variance, with *Time* (BrAC pre-task and post-task) as within-subject variable. Two subjects' B-BAES data and five subjects' BrAC scores were lost; the analysis was conducted with the remaining subjects. Behavioral data were analyzed with *Dose* (Placebo, Alcohol) and *Beverage Image Class* (Neutral, Alcohol Beverage Images) as within-subject factors. ERP data were analyzed with *Dose* (Placebo, Alcohol) and *Beverage Image Class* (Neutral, Alcohol Beverage Images) as within-subject variables. Further analysis for each ERP component focused on the channel locations where the amplitude was maximal. When appropriate, Greenhouse-Geisser corrected values were reported.

To assess whether ERP differences across sessions predicted unique variance in the change in alcohol use during the 6 months after the experiment, a hierarchical multiple regression analysis was conducted. First, subjects' demographic characteristics (age, gender, and education) were entered to the regression model, followed by the AUDIT score for recent use (sum of scores of items on frequency of drinking, typical quantity, and frequency of heavy drinking) at baseline from the version about the past 90 days. In the last step, the contrast scores (alcohol minus placebo) for the alcohol and the neutral stimulus sets were entered. This way the predictive value of acute alcohol effect on ERP indices was tested beyond the predictive value of subjects' demographics and AUDIT scores at baseline.

RESULTS

Questionnaires

Subjects' craving scores and their positive and negative mood scores at the start of the experiment were the same in the placebo and in the alcohol condition (p-values > 0.2).

Manipulation Checks

The differences in the BAES stimulation subscale before and after the task performance revealed that subjects felt less stimulated as the session proceeded ($F(1, 84) = 14.01$, $p < 0.001$, $\eta^2_p = 0.14$). Moreover, subjects felt more sedated after alcohol than after placebo ($F(1, 84) = 29.84$, $p < 0.001$, $\eta^2_p = 0.26$). BAL levels were lower post-task compared with pre-task ($F(1, 81) = 4.519$, $p = 0.037$, $\eta^2_p = 0.05$; see Table 1).

Behavioral Measures

Dose by beverage image class effect on hit rates. Hit rates trended towards a main effect of *Dose* ($F(1, 86) = 3.89$, $p = 0.052$, $\eta^2_p = 0.04$), an effect superseded by a significant interaction effect of *Dose* by *Beverage Image Class* ($F(1, 86) = 7.85$, $p = 0.006$, $\eta^2_p = 0.08$). On the average, hit-rates tended to be higher in the placebo condition. *Post hoc* analysis of the two-way interaction revealed that in the alcohol condition, hit-rates were higher for the *Alcohol Beverage Images* compared with the *Neutral Beverage Images* ($t(85) = -2.39$, $p = 0.02$), in the absence of such an effect in the placebo condition ($p > 0.15$). Moreover, hit-rates were higher for the *Neutral Beverage Images* in the placebo condition compared with the alcohol condition ($t(85) = 3.09$, $p = 0.003$), with no differences observed between conditions for the *Alcohol Beverage Images* ($p > 0.55$) (see Figure 2, left panel).

Table 1 Mean Scores and Standard Deviations for the BrAC and the Brief Biphasic Alcohol Effects Scale (B-BAES) Before (Pre-Task) and After (Post-Task) Subjects Completed the Go/NoGo Task in the Placebo and in the Alcohol Condition

	Pre-task	Post-task
BAL (g/l, (mean (SD)))	0.53 (0.31)	0.43 (0.19)*
B-BAES stimulation subscale		
Placebo (mean (SD))	16.75 (5.93)	14.76 (5.79)****
Alcohol (mean (SD))	16.14 (5.98)	14.75 (6.09)**
B-BAES sedation subscale		
Placebo (mean (SD))	11.39 (6.12)**** [a]	11.99 (5.64)**** [b]
Alcohol (mean (SD))	14.87 (6.96)**** [a]	15.92 (6.85)**** [b]

Abbreviation: BAL, blood alcohol level.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$, ****$p < 0.001$.
Significant differences for the sedation subscale are not across time points (pre *vs* post-task), but across conditions (placebo *vs.* alcohol). [a] and [b] indicates significant differences across conditions at pre- and post-task, respectively.

Effect of beverage image class on false alarms. False alarm rates revealed a main effect of *Beverage Image Type* ($F(1, 86) = 32$, $p < 0.001$, $\eta^2_p = 0.27$), subjects made more commission errors for the *Alcohol* than the *Neutral Beverage Images* (see Figure 2, middle panel).

Effect of dose on RT. In the trials with correct-go and commission responses, subjects tended to respond faster in the placebo than the alcohol condition (Correct-Go: $F(1, 86) = 3.56$ $p = 0.063$, $\eta^2_p = 0.04$; Commission: $F(1, 86) = 5.91$, $p = 0.017$, $\eta^2_p = 0.06$; See Figure 2, right panel).

N2

Dose by beverage image class effect on N2. The NoGo-N2 for the correct responses revealed a main effect of *Dose* ($F(1, 77) = 10.103$, $p = 0.002$, $\eta^2_p = 0.12$) and a main effect of Beverage Image Class ($F(1, 77) = 24.888$, $p < 0.001$, $\eta^2_p = 0.24$). An interaction effect of Block Type by Beverage Image Class qualified these main effects ($F(1, 77) = 6.021$, $p = 0.016$, $\eta^2_p = 0.073$). Inspection of the two-way interaction effect revealed that: (i) The NoGo-N2 for the *Alcohol Beverage Images* was larger than for the *Neutral Beverage Images,* both in the placebo and in the alcohol conditions (placebo: $t(77) = 5.47$, $p < 0.001$, alcohol: $t(77) = 2.02$,

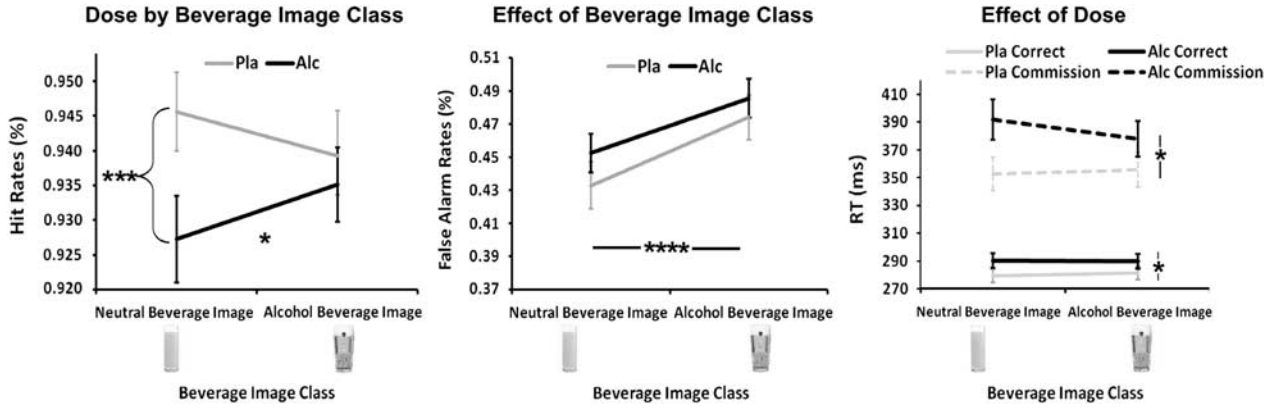

Figure 2 Behavioral results for hit rates (left side), false alarm rates (middle), and RT (right side). Hit rates were lower in alcohol condition for neutral beverage images. False alarm rates were lower for neutral beverage images. RTs for trials with commission errors and correct Go responses were shorter in the placebo condition. Alc, alcohol; Pla, placebo; Pla Correct, Correct go trials in the placebo condition; $*p<0.05$, $**p<0.01$, $***p<0.005$, $****p<0.001$.

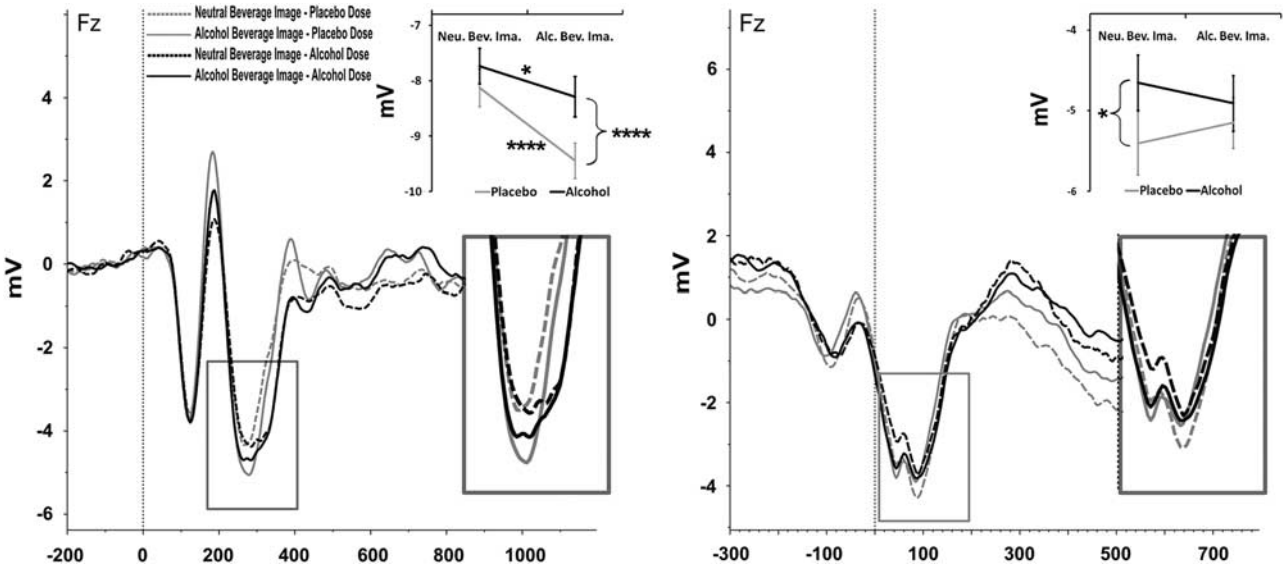

Figure 3 Stimulus-locked N2 (left side) for trials with correct responses and response-locked ERN for trials with error responses (right side) at Fz. Stimulus and response onset occurred at 0 ms. The NoGo-N2 for the *Alcohol Beverage Images* was larger than the *Neutral Beverage Images* in both placebo and alcohol conditions and acute alcohol decreased the amplitude of NoGo-N2 only for the *Alcohol Beverage Images (left side)*. The ERN was smaller in the alcohol than the placebo condition. Acute alcohol decreased the ERN only for the *Neutral Beverage Images (right side)*. Alc. Bev. Ima, alcohol beverage images; Neu. Bev. Ima, neutral beverage images; $*p<0.05$, $**p<0.01$, $***p<0.005$, $****p<0.001$.

$p=0.047$); (ii) For the *Neutral Beverage Images*, the NoGo-N2 had comparable amplitudes ($p>0.2$) after alcohol and placebo, however, for the *Alcohol Beverage Images*, acute alcohol decreased the amplitude of NoGo-N2, ($t(77)=-4.136$, $p<0.001$) (see Figure 3, left). NoGo-N2 for the incorrect trials did not reveal any main or interaction effects (p-values >0.07).

Error-Related Negativity

Dose by beverage image class effect on ERN. The ERN was smaller in the alcohol than the placebo condition ($F(1, 68)=4.073$, $p=0.048$, $\eta^2_p=0.057$) (see Figure 3, right panel). Given the predictive effects of the ERN (see below), additional exploratory pair-wise comparisons were conducted. These results revealed that acute alcohol decreased the ERN for the *Neutral Beverage Images* ($t(68)=-2.22$, $p=0.03$), but not for the *Alcohol Beverage Images* ($p>0.3$).

Neural Predictors of Alcohol Use After Six Months

Six months after the baseline assessment, 82.5% follow-up response rate was achieved in the full sample. On average, 'completers' and 'drop-outs' were similar on demographic characteristics, yet drop-outs scored higher on drinking-related problems (RAPI), contained more smokers and reported higher drug use frequency (see Supplementary Table S2). In the hierarchical multiple regression model,

	B	SE B	Beta	P - values
Step1: change R^2: .193, p=.019				
Gender	1.432	.539	.333	.01
Age	.317	.205	.194	.127
Middle level education	.149	.819	.036	.856
High level education	1.271	.797	.316	.117
Step2: change R^2: .425, p<.001				
Gender	.837	.382	.195	.033
Age	.318	.142	.194	.029
Middle level education	.564	.572	.136	.328
High level education	.675	.559	.168	.233
Audit baseline	.636	.083	.701	<.001
Step3: change R^2: .072, p=.005				
Gender	.86	.361	.2	.021
Age	.362	.131	.221	.008
Middle level education	.795	.53	.191	.139
High level education	.762	.515	.19	.145
Audit baseline	.714	.079	.787	<.001
ERN Contrast-AlcBevIma	-.241	.071	-.288	.001
ERN Contrast-NeuBevIma	.022	.057	.033	.694

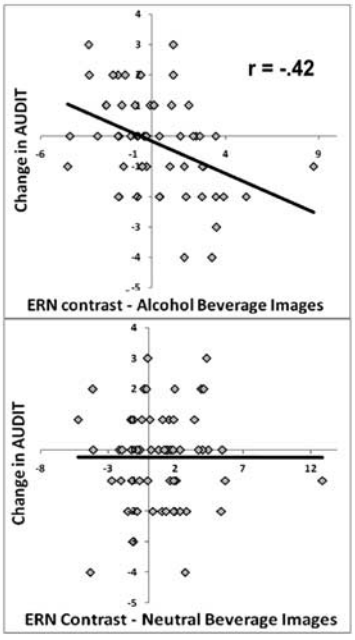

Figure 4 Hierarchical multiple regression analysis for variables predicting AUDIT at 6-month follow-up ($n = 59$) (left side). The correlation between change in AUDIT scores (AUDIT follow-up, last 90 days—AUDIT baseline, last 90 days), the ERN contrast (Alcohol—Placebo) for the Alcohol (upper, right) and Neutral Beverage Images (lower, right). AlcBevIma, alcohol beverage images; NeuBevIma, neutral beverage images; SE, Standard errors.

one subject's Cook's distance was 0.7 (mean Cook's Distance = 0.01, SD Cook's Distance = 0.03, before exclusion) and this subject was excluded from the analysis. The frontal ERN in the *Alcohol Beverage Images* significantly predicted future alcohol use beyond the variance explained by demographics and baseline AUDIT scores. The total variance explained by the full model was 69% (F $\text{change}_{2,51} = 5.886$, $p = 0.005$). The demographics and the baseline AUDIT scores explained 19.3% (F $\text{change}_{4,54} = 3.237$, $p = 0.019$) and 42.5% (F $\text{change}_{1,53} = 58.875$, $p < 0.001$) of the variance in alcohol use 6 months later, respectively. The frontal ERN in the *Alcohol Beverage Images* explained an additional 7.2% of the variance. To interpret the contribution of the ERP contrast in the *Alcohol Beverage Images*, we conducted a correlation analysis between change in AUDIT scores (AUDIT follow-up—AUDIT baseline), the ERN contrast in the alcohol and neutral blocks. The results revealed a negative correlation between change in AUDIT and the ERN contrast in the *Alcohol Beverage Images* ($r = -0.42$, $p = 0.001$) (see Figure 4). Subjects, who showed a relatively strong ERN decrease after acute alcohol in the alcohol blocks had lower AUDIT scores, relative to baseline, 6 months later.

DISCUSSION

We examined whether acute alcohol and alcohol cues affect conflict monitoring and error detection processes in drinking older adolescents. Moreover, we tested whether alcohol-induced changes on these cognitive processes predict future alcohol use. Behavioral data revealed that RT for commission and correct-go responses were slower after alcohol administration, suggesting a psychomotor slowing to maintain accuracy. In line with this interpretation, false alarm rates did not vary across the alcohol and placebo conditions. Similar to previous findings (Adams *et al*, 2013; Kreusch *et al*, 2013), subjects gave more go responses for alcohol cues both in Go and NoGo trials, suggesting that alcohol cues may be more associated with an approach or a go response. Moreover, hit rates for neutral cues were more sensitive to acute alcohol effects; subjects made more omissions for neutral cues after acute alcohol.

The ERP data showed that the NoGo-N2 for alcohol cues was higher than for soft drink cues, suggesting a relatively strong simultaneous activation of Go (stimulus-induced) and NoGo (task-induced) responses towards alcohol cues. In line with previous simulation research (Yeung and Cohen, 2006), acute alcohol decreased the N2 specifically for task-irrelevant alcohol cues. The ERN was not influenced by the motivationally salient alcohol cues. Exploratory analyses revealed lower ERN amplitudes after acute alcohol, specifically for neutral cues. Finally, alcohol-induced changes in the ERN for alcohol cues predicted changes in alcohol use 6 months later.

In young adult drinkers, many studies have shown increased salience of alcohol-related stimuli (Herrmann *et al*, 2000; Bartholow *et al*, 2007; 2010), engagement of attentional resources, and automatic approach tendencies towards alcohol cues (Johnsen *et al*, 1994; Sharma *et al*, 2001; Field *et al*, 2008). Thus, the results of the Nogo-N2 associated with inhibition and conflict monitoring might indicate that alcohol cues pre-activate a go response because of increased attention allocation and approach tendencies. In correct NoGo trials, the greater N2 for alcohol cues might suggest that when increased conflict between stimulus-induced and task-relevant responses is detected, inhibition of this prepotent response has been successful. In incorrect NoGo

trials, the lack of this additional process of conflict detection might have resulted in comparable N2 amplitudes for alcohol and non-alcohol cues. Moreover, the ERN associated with error detection was smaller for alcohol cues during commission errors, a result in line with the idea that detecting the conflict between competing responses might be important for giving correct responses. Moreover, relatively small ERN amplitudes for alcohol cues might suggest a relative dysfunction involving error detection in the presence of alcohol cues.

To the best of our knowledge, only two previous studies investigated the influence of drug-related context on the N2, one in the context of smoking cues (Luijten *et al*, 2011) and the other in the context of alcohol cues (Petit *et al*, 2012). These studies did not reveal any effects of drug-related cues on the N2. Both studies implemented alcohol-related contexts as backgrounds; the feature that signaled the correct response was not itself drug-related. This may have allowed the drug-related stimuli to be more effectively suppressed. The study by Luijten *et al* (2011) implemented intermittent presentation of drug-related and control cues, unlike our continuous presentation of drug cues in a blocked design. Rapid attention alterations required by the task might have reduced the effect of task-irrelevant stimulus information on the N2. Differences across studies could also be because of studying different populations. The current study tested such effects with a younger sample, likely to have heightened reward sensitivity.

A second aim of the current study was to examine whether alcohol-induced changes on ERPs associated with action monitoring would predict changes in alcohol use. The effect of acute alcohol in the ERN for alcohol cues predicted changes in alcohol use in adolescents. Subjects for whom alcohol disrupted the error detection processes for alcohol cues, as indexed by the ERN, were more likely to show a decrease in their drinking at the 6-month follow-up. A tangible deleterious effect of acute alcohol on the ERN for alcohol cues might indicate a 'protective sensitivity', comparable with the protective value of negative alcohol effects on body sway (cf., Schuckit *et al*, 2000). An earlier study showed that expectancy of cognitive and motor impairment due to alcohol is associated with non-drinking in adolescents and young adults (Wiers *et al*, 1997). Moreover, individuals with high sensitivity to negative alcohol effects are more likely to show adaptive strategy adjustments (Bartholow *et al*, 2003). Taken together, alcohol-induced changes in the monitoring system might be a protective factor for alcohol abuse.

In summary, the results of the current study are in line with previous studies showing decreased performance in the presence of motivational cues. We showed that the conflict monitoring system is sensitive to alcohol cues. This could be because cues signaling reward opportunities might activate a go response mode. Future research is needed to replicate and extend the current findings in adults with substance use disorders. Moreover, low and high doses of alcohol affect different processes; therefore, future studies in adult populations could study the acute effects of higher dosages of alcohol and relate them to future alcohol use. Responses of the error detection system towards drugs and drug-related stimuli appear to be related to changes in drug-related behaviors. An interesting route for future studies would be to understand how sensitivity to positive and negative response outcomes (ie, feedback-based learning) could affect processes such as error detection and conflict monitoring in adolescents and how these learning processes could contribute to addictive behaviors in later life. Lastly, we would like to note that until now, our knowledge of acute alcohol effects on neurocognitive processes in younger samples have exclusively been based on either relatively old adolescents because of legal limitations or animal studies, hence the current study uniquely contributes to the literature by providing initial findings of acute alcohol effects on human adolescent population.

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