An Event-related Potential Study of Error-monitoring Deficits in Female College Students Who Participate in Binge Drinking

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Objective: This study investigated error-monitoring deficits in female college students with binge drinking (BD) using event-related potentials (ERPs) and the modified Flanker task.
Methods: Participants were categorized into BD (n=25) and non-BD (n=25) groups based on the scores of the Korean-version of the Alcohol Use Disorder Identification Test (AUDIT-K) and the Alcohol Use Questionnaire (AUQ). The modified Flanker task, consisting of congruent (target and flanker stimuli are the same) and incongruent (target and flanker stimuli are different) conditions, was used to evaluate error-monitoring abilities.
Results: The BD group exhibited significantly shorter response times and more error rates on the Flanker task, as well as reduced error-related negativity (ERN) amplitudes compared with the non-BD group. Additionally, ERN amplitudes measured at FCz and Cz were significantly correlated with scores on the AUDIT-K and AUQ in the whole participants. The BD and non-BD groups did not show any significant differences in error positivity amplitudes.
Conclusion: The present results indicate that college students with BD have deficits in error-monitoring, and that reduced ERN amplitudes may serve as a biological marker or risk factor of alcohol use disorder.

KEY WORDS: Alcohol drinking; Error positivity; Error negativity; Event-related potentials; Inhibition; Young adult.

INTRODUCTION

Binge drinking (BD), a pattern of excessive alcohol consumption followed by a period of abstinence, is defined on the basis of the quantity, frequency and speed of alcohol consumption.[1,2] BD has recently gained attention as a major health problem, particularly in college students, because BD is most prevalent among this population,[3,4] causes serious academic and interpersonal problems,[5] and increases the likelihood of developing alcohol use disorder (AUD).[6,7] Patients with AUD and individuals participating in BD share common abnormalities in brain structure/function and neuropsychological function.[8,9] For example, structural/functional abnormalities in hippocampus and prefrontal cortex,[10,11] and executive dys-

functions, including working memory,[12] planning,[13] attention,[14] inhibition,[15] are observed both in BD and AUD.

Individuals with AUD are characterized by the inability to inhibit drinking behavior[16] and failure to learn from previous harmful behavior.[17] In other words, these individuals have deficits in self-control. Error-monitoring, an ability to monitor one's own behavior, including error detection and adjustment of one's behavior for the intended purposes,[18,19] is a fundamental psychological process to self-control behavior. Therefore, impaired error-monitoring could result in failure to monitor excessive alcohol intake and to correct or adjust drinking behavior after slips, which, in turn, lead to the development of AUD.[17,20] Deficits in error-monitoring are observed in patients with AUD[21] and young heavy drinkers.[20,22,23]

Neuroimaging studies have provided the neurological substrates underlying deficits in error-monitoring observed in patients with AUD or individuals who drink heavily. The anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex are involved in error-monitoring.[19,24,25] The prefrontal cortex is particularly vulner-

able to alcohol,[26-28] and structural abnormalities and dysfunctions in the prefrontal cortex and ACC are observed in patients with AUD and individuals with BD. For example, reduced prefrontal cortex volume[29] and blood flow to the prefrontal cortex[30] are observed in patients with AUD. In addition, reduced thickness of the ACC[31] and prefrontal activation[32] are observed in individuals with BD, whereas reduced ACC volume is observed in adolescent heavy drinkers.[33]

Although neuroimaging studies have contributed to revealing the brain structures involved in error-monitoring, they provide little information regarding sequential activations of brain areas involved in error-monitoring. Due to the high temporal resolution, event-related potentials (ERPs) are widely used to investigate cognitive functions.[34] ERPs are particularly useful for measuring error-monitoring, which is elicited rapidly in a very short period.[35,36]

Studies that have investigated error-monitoring using ERPs have consistently reported error-related negativity (ERN) and error positivity (Pe) as electrophysiological indices of error-monitoring. ERN is a negative peak observed 50 to 150 ms after incorrect responses, whereas Pe, a positive peak occurring after ERN, is observed 150 to 400 ms after erroneous response.[37-40] ERN and Pe reflect different stages of error processing.[41] Previous studies suggested that ERN reflects initial and automatic error detection[42] or the magnitude of the individual's responses to his/her own errors.[38] Although the functional significance of Pe is less understood than ERN,[41] it has been suggested that Pe reflects the conscious awareness of errors[41,43] and the motivation to correct the errors,[44] because greater Pe amplitudes are observed after consciously recognized errors than after unrecognized errors.[45,46]

Previous studies which investigated the effect of alcohol on error-monitoring using ERPs have reported that normal participants who consume alcohol exhibit reduced ERN and Pe amplitudes[47,48] or only reduced ERN amplitudes[44] compared with those who do not consume alcohol. Young heavy drinkers also show reduced ERN amplitudes[22,23] or reduced Pe amplitudes[49] compared with those who do not regularly drink heavily. In contrast, Smith et al.[20] reported increased ERN amplitudes in female but not in male heavy drinkers compared with controls, resulting in overall non-significant ERN amplitudes between heavy drinkers and controls. Schellekens et al.[50]

reported increased ERN amplitudes in patients with AUD, particularly in those with a comorbid anxiety disorder, compared with controls. In addition, Smith et al.[51] did not observe significant differences in ERN or Pe amplitudes between young heavy drinkers and controls. These inconsistent findings suggest that alcohol consumption affects error-monitoring differently depending on gender and anxiety comorbidity.

The Flanker task is widely used to measure error-monitoring[52,53] because this task elicits errors by manipulating the level of difficulty.[54] In the Flanker task, it is required for participants to attend to a target stimulus presented in the center, while ignoring the flanker stimuli presented to the right and left of the target stimulus. The Flanker task consists of congruent condition, under which the target and flanker stimulus figures are the same, and incongruent condition, under which the target and flanker stimulus figures differ. A longer response time and more errors are observed under the incongruent condition than the congruent condition, which is called the Flanker congruency effect.[52,55] Normal individuals who consume alcohol exhibit increased response time and decreased accuracy on the Flanker task than those who do not consume alcohol.[56]

Although a few recent studies have investigated error-monitoring using ERPs in young heavy drinkers who were selected based on the quantity of alcohol consumption[20,22,23,51] no study had investigated error-monitoring ability in college students with BD using ERPs. Females who participate in BD exhibit more impaired functions than BD males,[57,58] and different performance patterns are observed on an error-monitoring task depending on gender[20] and anxiety disorder comorbidity.[50] These results indicate that gender differences should be considered in BD studies.

Given this background, we investigated error-monitoring ability in female college students who participated in BD using ERPs and the modified Flanker task while controlling for anxiety and depression. We hypothesized that college students with BD would have error-monitoring deficits that would be reflected by poorer performances on the Flanker task and smaller ERN and/or Pe amplitudes than those who did not participate in BD.

METHODS

Participants

We administered the Korean version of the Alcohol Use Disorder Identification Test (AUDIT-K)[59,60] and the Alcohol Use Questionnaire (AUQ)[61] to 250 female college students through webhard. BD was defined on the basis of the quantity, frequency and speed of alcohol consumption; drink 5 (male) or 4 (female) glasses more than once during the previous 2 weeks[1] and drink 3 (male) or 2 (female) glasses per hour.[2]

The World Health Organization recommends a score of >8 on the AUDIT as a cut-off[59]; however, others have suggested that the sensitivity and specificity for the problem drinking are highest when a score of 12 on the AUDIT is used as cut-off.[60,61] Additionally, a score of >26 on the AUDIT indicates the possibility of alcohol dependence.[62]

Therefore, in this study, those who obtained total scores of 12 to 26 on the AUDIT, drank four glasses more than once during the previous 2 weeks, and drank more than two glasses per hour (measured by AUQ item 10), were included in the BD group. Those who obtained total scores <8 on the AUDIT, did not drink four glasses during the last 2 weeks, and drank less than one glass per hour, were included in the non-BD group. One glass contains approximately 12-g ethanol.

We administered the Structured Clinical Interview for DSM-IV Axis I disorder, research version, non-patient edition (SCID-I-NP)[63] to ensure that no participant had psychiatric or neurological disorders. Parents' alcohol use can affect their offspring's alcohol use.[64] Therefore, the Children of Alcoholics Screening Test (CAST)[65] was administered to identify whether the participants' parents had a history of AUD, and those who obtained a score >6 on the CAST were excluded.

The intelligence level of participants was evaluated by the Korean version of the Wechsler Adult Intelligence Scale.[66] The Self-Rating Depression Scale (SDS)[67] and the State-Trait Anxiety Inventory (STAI)[68] were used to evaluate depression and anxiety, respectively.

Forty-two and forty students were satisfied with the criteria for BD and non-BD, respectively. However, those with left-handedness, ambidexterity and history of psychiatric disorders were excluded, and finally 25 students each were included in the BD and non-BD groups. All participants were instructed to abstain from using alcohol for 48 hours prior to the experiment. This study was approved by the Institutional Bioethics Review Board of Sungshin Women's University (No. SSWUIRB2015-060). All participants provided written informed consent after receiving a complete description of the study, and they were paid for their participation.

Alcohol Use Disorder Identification Test

The AUDIT[59] is a 10-item self-administered questionnaire that is used to measure the quantity and frequency of alcohol consumption, the presence of alcohol dependence, and psychosocial problems related to alcohol consumption.

Alcohol Use Questionnaire

In this study, items 10, 11, and 12 of the AUQ were used to evaluate the speed of drinking (average drinks per hour), number of times binge drunk in the previous 6 months, and percentage of times getting drunk when drinking, respectively.[61] Additionally, the binge score was calculated as [4×(Item 10)+Item 11+0.2×(Item 12)] in order to estimate the severity of BD.[69]

The Flanker Task

The modified Flanker task[70] was developed to compensate for the low level of difficulty of the original Flanker task and to measure error-monitoring. The stimuli were presented on the computer monitor (Fig. 1A), and a response panel containing buttons designated to the direction of the target stimulus was placed in front of the monitor (Fig. 1B).

Four types of triangles indicating up/down and left/right directions were used as target stimuli, and the participants were required to press the button designated to the direction of the target stimulus as rapidly and accurately as possible. The target stimulus was presented in the center on a monitor, and the flanker stimuli were presented to the left/right of the target stimulus. In a congruent condition, the directions of the target and flanker stimuli were the same (Fig. 2A), whereas the directions of the target and flanker stimuli were different in an incongruent condition (Fig. 2B).

In this study, each triangle produced one congruent and three incongruent conditions. More errors and reduced ERN amplitudes are observed in the incongruent condition than the congruent condition.[70] Thus, in this
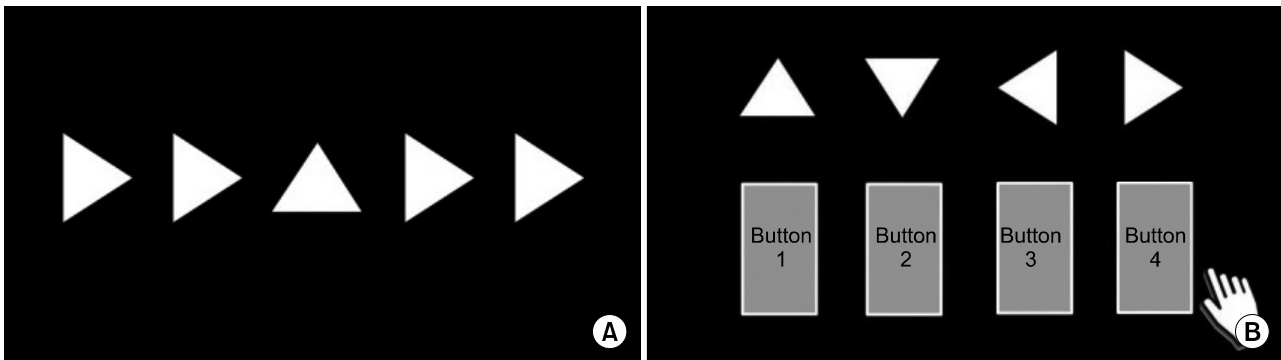
Fig. 1. (A) The Flanker task consists of one target stimulus (center) and four flanker stimuli (left/right of the target stimulus). The stimuli are presented on the computer monitor. (B) The response panel containing response buttons designated for the direction of the target stimulus is placed in front of the computer monitor. Participants are instructed to press one of four buttons designated for the direction of the target stimulus.
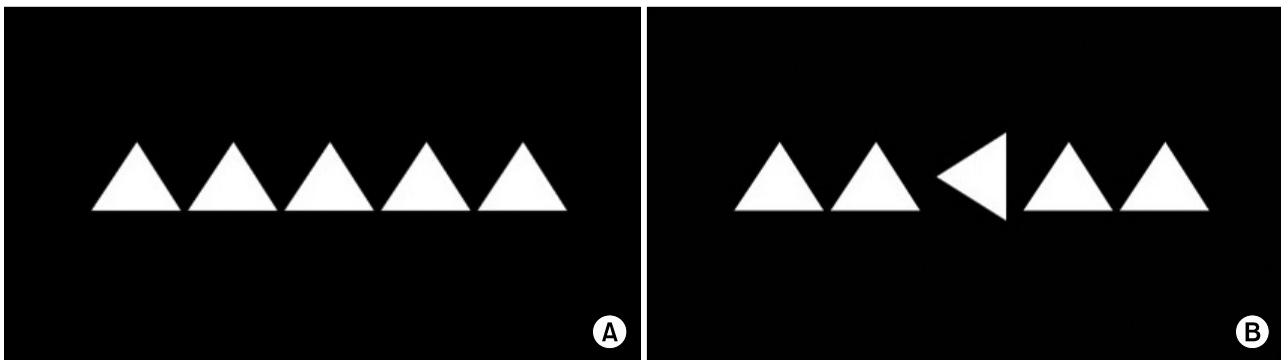

Fig. 2. The Flanker task condition. (A) In the congruent condition, the directions of target stimulus and flanker stimuli are same. (B) In the incongruent condition, the directions of target stimulus and flanker stimuli are different.

study, congruent and incongruent conditions were presented at the rate of 4:6. In other words, we presented incongruent conditions more frequently than congruent conditions to adjust the level of difficulty. A total of 800 trials (320 congruent conditions and 480 incongruent conditions) were administered randomly in four blocks and the location of the response button designated to the target stimulus was changed across the blocks.

The crosshair was displayed for 700 ms, then the stimuli were presented for 80 ms followed by 1,200-ms response time. The inter-stimulus interval was 1,980 ms. E-PRIME (Psychological Software Tools Inc., Sharpsburg, PA, USA) was used for these operations. A block of 60 trials was administered to ensure that all participants understood the instructions prior to the experimental session. The procedure of the Flanker task is presented in Figure 3.

Electrophysiological Recording Procedure

A 64-channel HydroCel Geodesic Sensor Net con-

nected to a 64-channel, high-input impedance amplifier (Net Amp 300; Electrical Geodesics, Eugene, OR, USA) was used to record electroencephalographic (EEG) activity in an electrically shielded and soundproofed experimental room. All of the electrodes were referenced to Cz, and eye movements and blinks were monitored by electrodes positioned near the outer canthus and beneath the left eye. Impedance was maintained at 50 kΩ or less.[71]

EEG was recorded continuously using a 0.1 to 100 Hz analog bandpass and a sampling rate of 500 Hz during the experiment. After data collection, the EEG measured in the congruent and incongruent conditions was segmented into 600 ms epochs (including a 100 ms pre-response baseline). The epochs was baseline-corrected, and those contaminated by artifacts were rejected prior to averaging (the threshold for artifact rejection was a peak-to-peak amplitude of ±70 μV). All data associated with incorrect responses were averaged with an average-reference transformation, and the ERPs were digitally low-pass
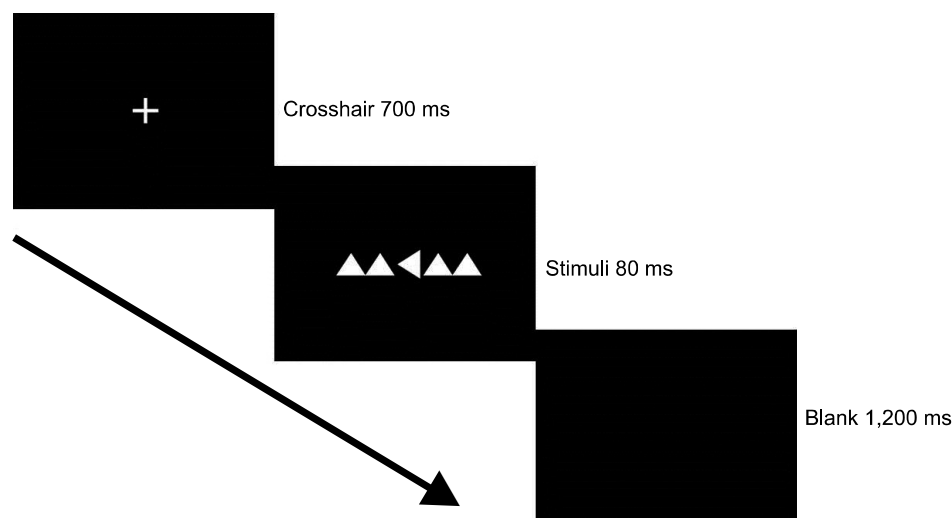
Fig. 3. The procedure of the Flanker task.

filtered at 30 Hz. The mean numbers of trials included in the ERN/Pe analysis for the BD and non-BD groups were 72.36 (standard deviation [SD], 10.31) and 42.72 (SD, 8.37), respectively. The two groups differed in terms of trials for averaging ERN/Pe (t[48]=3.09, $p<0.01$), as the BD group committed more errors on the Flanker task than did the non-BD group.

Statistical Analysis

Based on visual inspections of the grand-averaged (Fig. 4) and individual ERP waveforms, the ERN and Pe time windows were determined. ERN was defined as the most negative peak in a 50 to 150 ms period after onset of erroneous responses, whereas Pe as the most positive peak in a 150 to 400 ms period after the onset of erroneous responses. Separate mixed-design repeated measures analysis of variance (ANOVA) was used to analyze the amplitudes and latencies of ERN and Pe. The electrode site (F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, P3, Pz, and P4) was a within-subject factor and group (BD and non-BD groups) was a between-subjects factor. Green-Geisser corrections were utilized for violations of sphericity, and the corrected p values are reported when appropriate. The relationships between ERN/Pe amplitudes and scores on the BD measures were analyzed by Pearson's product-moment correlation analysis. Demographic characteristics were analyzed by the independent t test, and the behavioral performances of the Flanker task were analyzed by mixed design ANOVA, using condition as a within-subject factor (congruent and incongruent conditions) and group as a between-subject factor.

Statistical analyses were carried out with SPSS version 20 for Windows (IBM Corp., Armonk, NY, USA).

RESULTS

Demographic Characteristics

The BD and non-BD groups did not differ in terms of age (t[48]=−0.45, not significant [ns]), educational level (t[48]=−0.85, ns), intelligence quotient (t[48]=0.17, ns), SDS (t[48]=0.88, ns), state anxiety on the STAI (t[48]= 0.42, ns), or trait anxiety on the STAI (t[48]=0.90, ns). However, the BD group showed significantly higher total AUDIT-K score (t[48]=19.20, $p<0.001$), drinking speed (t[48]=10.42, $p<0.001$), number of times being drunk in the previous 6 months (t[48]=3.67, $p<0.01$), percentage of times getting drunk when drinking (t[48]=3.82, $p< 0.001$), and binge score on the AUQ (t[48]=8.06, $p< 0.001$) than those in the non-BD group. The demographic characteristics of the two groups are presented in Table 1.

Behavioral Performance on the Flanker Task

The statistical analysis of error rates showed the main effects of group (F[1,48]=10.27, $p<0.001$) and condition (F[1,48]=49.68, $p<0.001$). The BD group exhibited significantly higher error rates than did the non-BD group, and more errors were elicited in the incongruent condition than the congruent condition. In addition, an interaction effect was detected for group×condition (F[1,48]= 5.39, $p<0.05$). The BD group showed significantly higher error rates in congruent (F[1,48]=7.44, $p<0.05$) and incongruent conditions (F[1,48]=11.06, $p<0.05$) than
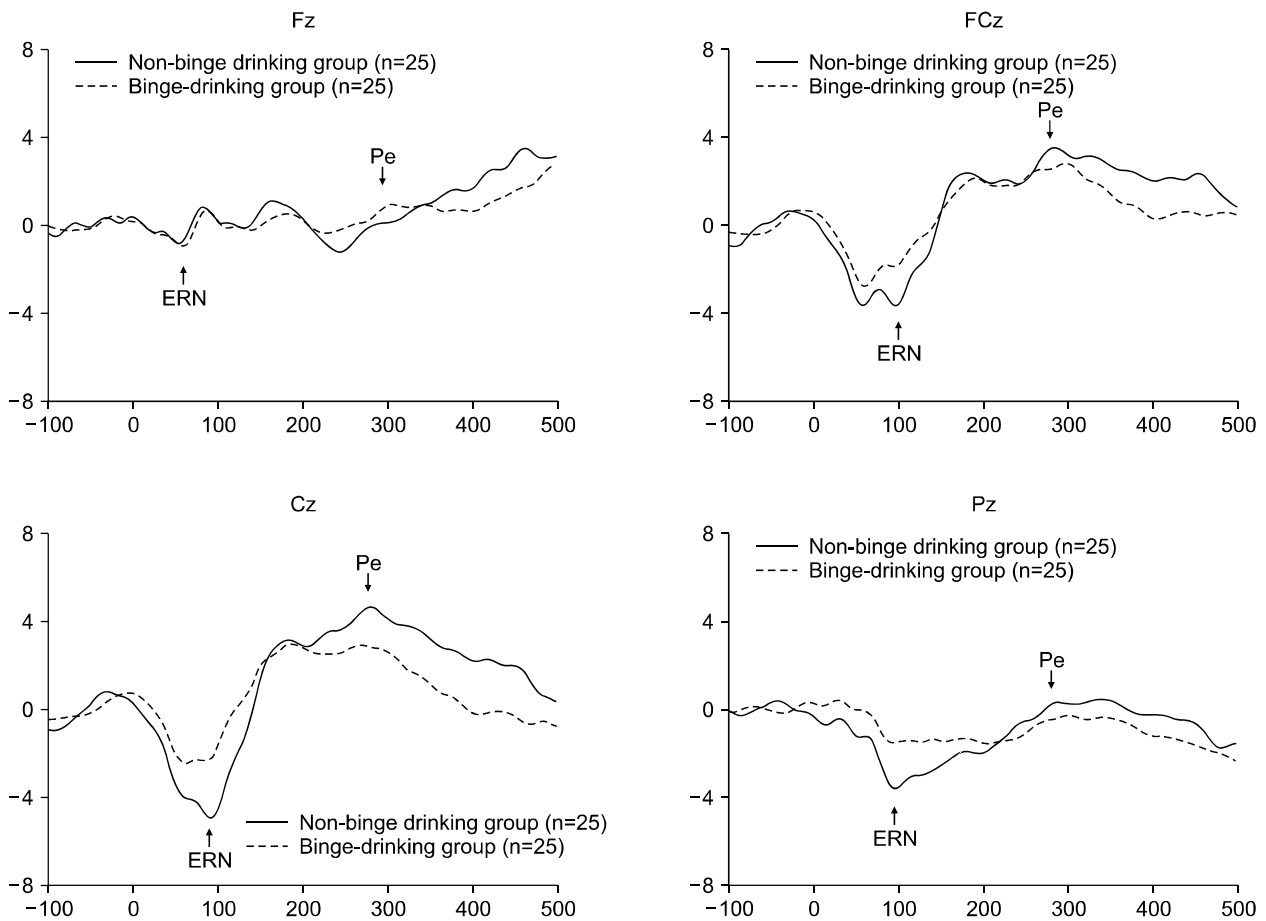
Fig. 4. The grand-averaged event-related potentials elicited by erroneous responses at Fz, FCz, Cz, and Pz for non-binge drinking and binge-drinking groups.
Pe, error positivity; ERN, error-related negativity.

Table 1. Demographic characteristics of non-binge drinking and binge-drinking groups

Chracteristic	Non-binge drinking (n=25)	Binge-drinking (n=25)	t
Age (yr)	21.72±2.44	21.44±1.89	−0.45
Education (yr)	15.20±1.32	14.92±1.00	−0.85
IQ	114.40±7.05	114.76±7.64	0.17
SDS	41.76±7.32	43.52±6.68	0.88
STAI state	42.08±9.21	43.28±11.00	0.42
STAI trait	43.36±9.23	45.76±9.71	0.90
AUDIT-K	1.68±2.06	19.04±4.03	19.20***
Speed of drinking (drinks/hr)	0.84±0.55	4.24±4.54	10.42***
Times drunk in the last 6 months	0.16±0.47	9.80±13.14	3.67**
Percentage of times became drunk when drinking	18.00±33.88	53.48±31.80	3.82***
AUQ binge drinking score	7.12±6.80	37.92±17.86	8.06***

Values are presented as mean±standard deviation.
IQ, intelligence quotient; SDS, Self-Rating Dpression Scale; STAI, Spieberger's State-Trait Anxiety Inventory; AUDIT-K, The Korean version of Alcohol Use Disorder Identify Test; AUQ, Alcohol Use Questionnaire.
**$p<0.01$, ***$p<0.001$.

those in the non-BD group.

The main effects of group (F[1,48]=8.23, $p<0.01$) and condition (F[1,48]=200.66, $p<0.001$), were observed for

response time. The BD group showed significantly shorter response times than those of the non-BD group in the congruent (F[1,48]=9.07, $p<0.01$) and congruent conditions

Table 2. Mean error rate and response time in non-binge drinking and binge-drinking groups

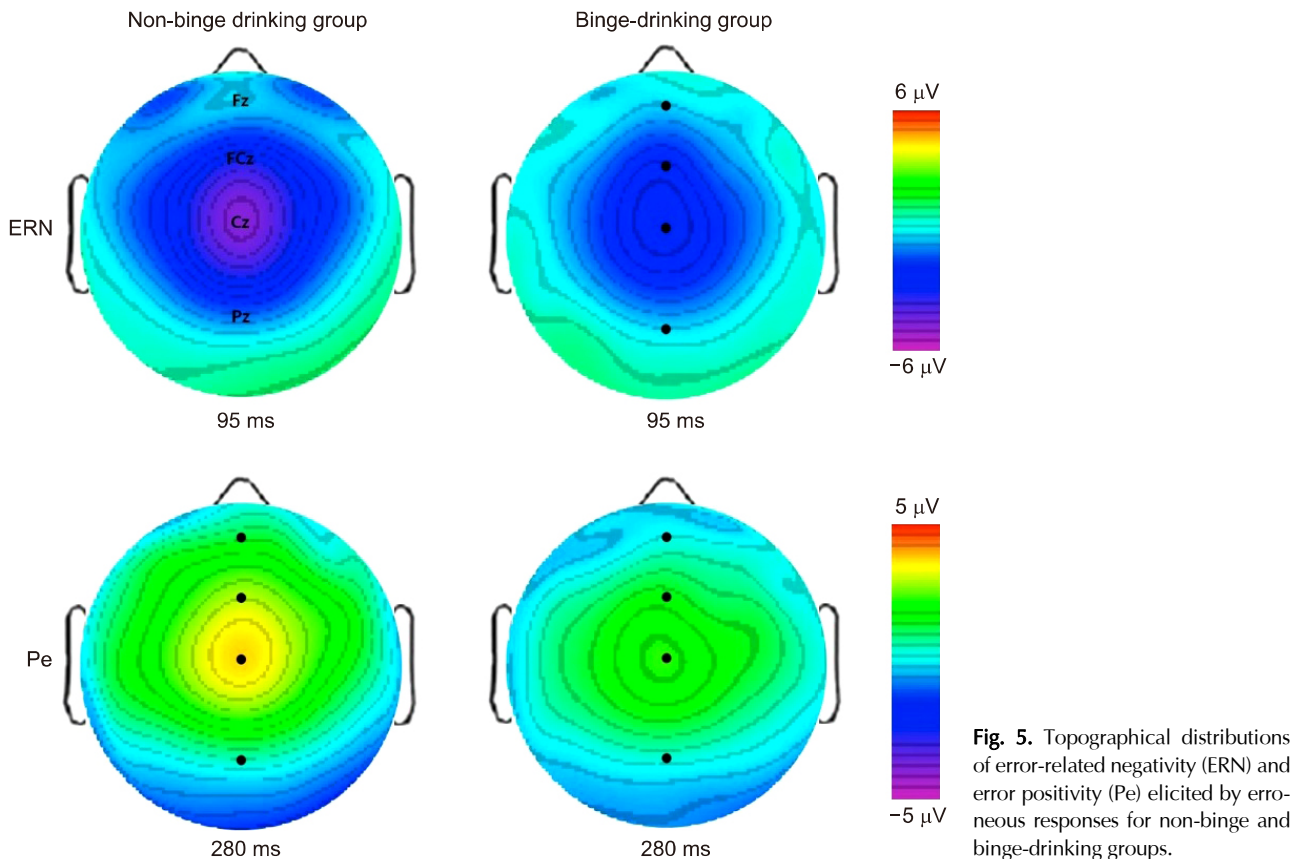|	Non-binge drinking (n=25)		Binge-drinking (n=25)	
	Congruent	Incongruent	Congruent	Incongruent
Error rate (%)	6.08±4.05	8.28±4.66	9.44±4.64	13.80±6.87
Response time (ms)	533.23±68.64	564.44±72.62	481.63±66.80	507.23±61.19

Values are presented as mean±standard deviation.

Fig. 5. Topographical distributions of error-related negativity (ERN) and error positivity (Pe) elicited by erroneous responses for non-binge and binge-drinking groups.

($F[1,48]=7.25$, $p<0.05$). The response time elicited by the incongruent condition was significantly longer than the response time elicited by the congruent condition. No interaction effect of group×condition was observed ($F[1,48]=1.96$, ns). The mean error rates and response times of the BD and non-BD groups are presented in Table 2.

Electrophysiological Measures

The grand-averaged ERPs elicited by erroneous responses at midline sites (Fz, FCz, Cz, and Pz) were displayed in Figure 4. Both the BD and non-BD groups exhibited ERN and Pe; however, BD group showed smaller ERN amplitudes, particularly at the Cz site, than did the non-BD group. The topographical distributions in elec-

trical activity measured at all electrode sites when the largest ERN and Pe amplitudes were observed are presented in Figure 5.

An analysis of the ERN amplitudes revealed the main effects of group ($F[1,48]=15.58$, $p<0.001$) and electrode site ($F[11,528]=12.27$, $p<0.001$). The BD group exhibited significantly smaller ERN amplitudes than did the non-BD group. The largest ERN amplitude was observed at Cz (-3.65 μV) and the smallest amplitude at F4 (-0.59 μV). In addition, an interaction effect of group×electrode site was observed ($F[11,528]=3.42$, $p<0.001$). The BD group exhibited significantly smaller ERN amplitudes at FCz, C3, Cz, C4, P3, Pz, and P4 than non-BD group. A main effect of electrode site was observed with respect to

Table 3. Mean error-related negativity amplitudes and latencies in non-binge drinking and binge-drinking groups

Site	Non-binge drinking (n=25)		Binge-drinking (n=25)	
	Amplitude (μV)	Latency (ms)	Amplitude (μV)	Latency (ms)
F3	−0.67±2.66	58.72±18.37	−0.79±2.75	65.04±16.40
Fz	−0.89±2.33	56.00±17.36	−0.98±2.42	60.24±15.71
F4	−0.54±2.01	60.64±17.35	−0.64±2.43	60.96±13.54
FC3	−2.04±1.82	96.80±16.87	−1.07±2.46	96.08±17.42
FCz	−3.88±1.84	96.00±16.04	−1.93±2.53	95.84±15.43
FC4	−1.58±1.99	94.24±16.71	−0.67±2.21	94.24±18.58
C3	−2.62±1.76	94.80±16.50	−1.04±1.96	96.08±16.24
Cz	−5.12±1.94	92.24±15.31	−2.18±2.60	90.00±14.64
C4	−2.36±1.83	94.56±15.65	−0.59±1.33	92.56±15.91
P3	−2.82±2.23	94.64±13.20	−1.19±1.89	96.16±11.72
Pz	−3.67±2.18	96.16±14.14	−1.55±1.76	96.48±12.93
P4	−2.87±1.52	96.64±14.24	−1.17±1.39	92.00±10.38

Values are presented as mean±standard deviation.

Table 4. Mean error positivity amplitudes and latencies in non-binge drinking and binge-drinking groups

Site	Non-binge drinking (n=25)		Binge-drinking (n=25)	
	Amplitude (μV)	Latency (ms)	Amplitude (μV)	Latency (ms)
F3	0.27±2.93	278.40±19.36	0.13±2.68	278.48±14.56
Fz	0.53±3.09	283.28±20.39	0.92±2.79	285.36±19.68
F4	0.92±3.13	283.60±21.23	0.80±2.82	285.92±16.23
FC3	1.38±2.46	281.04±16.29	0.61±2.02	285.52±14.99
FCz	3.57±3.61	280.00±17.14	2.78±2.71	286.00±17.97
FC4	2.48±3.09	279.64±19.67	1.20±2.14	286.72±17.41
C3	1.89±3.01	284.16±15.96	0.47±2.09	282.08±18.03
Cz	4.96±3.73	281.60±22.12	2.82±3.05	277.12±20.01
C4	2.33±2.78	283.28±18.87	1.14±1.87	282.64±16.71
P3	0.95±2.29	279.92±20.72	0.15±2.28	283.20±16.58
Pz	0.39±2.84	280.00±20.00	0.32±2.73	285.52±15.16
P4	0.96±1.85	280.48±18.64	0.44±2.09	285.76±17.93

Values are presented as mean±standard deviation.

ERN latency (F[11,528]=69.85, $p<0.001$). The shortest ERN latency was observed at Fz (58.12 ms), and the longest was observed at FC3 (96.44 ms). No significant main effect of group (F[1,48]=0.02, ns) or interaction effect of group×electrode site (F[11,528]=0.59, ns) was observed. The mean ERN amplitudes and latencies for the BD and non-BD groups are presented in Table 3.

With regard to Pe amplitude, a main effect of electrode site was observed (F[11,528]=13.07, $p<0.001$). The Pe amplitude measured at Cz was the largest (3.89 μV), and the smallest amplitude was at Fz (0.20 μV). However, no significant main effect of group (F[1,48]=3.02, ns) or interaction effect of group×electrode site (F[11,528]=1.08, ns) was observed. In terms of Pe latency, no significant main effect of group (F[1,48]=0.80, ns), electrode site (F[11,528]=

0.65, ns), or interaction effect of group×electrode site (F[11,528]=0.60, ns) was observed. The mean Pe amplitudes and latencies for the BD and non-BD groups are presented in Table 4.

Correlations between ERN Amplitudes and BD Severity

There were not any significant correlations between ERN amplitudes and scores on the AUDIT-K or AUQ in either BD group or non-BD group. However, significant correlations were detected between the total score on the AUDIT-K and the ERN amplitude measured at FCz (r=0.40, $p<0.05$) and Cz (r=0.54, $p<0.05$) in the whole participants. In addition, significant correlations were observed between binge score on the AUQ and the ERN am-

plitudes measured at FCz (r=0.47, $p<0.05$) and Cz (r=0.40, $p<0.05$) in the whole sample. These results indicate that more BD leads to more reduced ERN amplitudes.

DISCUSSION

We used ERPs and the modified Flanker task to investigate whether female college students with BD had error-monitoring deficits. The BD group exhibited significantly more errors and shorter response times on the Flanker task compared with the non-BD group, indicating that individuals with BD have deficits in error-monitoring. The present findings are consistent with previous studies reporting higher error rates[51] and shorter response times[72-74] in heavy drinkers compared with non-heavy drinkers. In the present study, the BD group showed more errors not only in the incongruent but also in the congruent conditions, which did not provide any response conflict compared with non-BD group. Higher error rates and faster response times in both conditions observed in individuals with BD seem to be related to the impulsivity these individuals have, since rapid response observed in heavy drinkers is related to the high level of impulsivity[72] and college students with BD show higher impulsivity than those with non-BD.[75] Unfortunately impulsivity was not assessed in this study.

The BD group showed significantly reduced ERN amplitudes than those in the non-BD group, consistent with previous findings.[22,47,48] For example, Ridderinkhof et al.[44] reported that normal controls who consume alcohol exhibit reduced ERN amplitudes than those who do not consume alcohol. In addition, Smith and Mattick[22] observed reduced ERN amplitudes in young female heavy drinkers than non-heavy drinkers.

Since ERN is known to reflect error detection[42] or the magnitude of an individual's responses to his/her own errors,[38] the reduced ERN amplitudes observed in the present study may indicate that individuals with BD have difficulties in monitoring their internal behavior. Previous studies have reported that the ACC is the generator of the ERN.[39,76] For example, Ullsperger and von Cramon[19] found that greater ACC activation is elicited after incorrect responses than correct responses, and O'Connell et al.[77] found that ERN is generated in the ACC by employing source localization analysis. Stemmer et al.[78] did not ob-

serve ERN in patients with ACC lesions. In addition, reduced thickness of the ACC is observed in individuals with BD[31] and reduced ACC volume is observed in adolescent heavy drinkers.[33] These imaging studies support the interpretation that reduced ERN amplitudes observed in the present study indicate dysfunctional error-monitoring controlled mainly by ACC. In addition, total score on the AUDIT-K and the binge score on the AUQ were positively correlated with ERN amplitudes measures at FCz and Cz. In other words, a greater amount and more frequent alcohol consumption are related to more reduced ERN amplitudes. All these findings indicate that observed smaller ERN amplitudes in individuals with BD are likely associated with structural abnormalities and dysfunctions in the ACC, which is involved in behavioral monitoring or inhibition.

Contrary to the present and previous findings, enhanced ERN amplitudes[20] or comparable ERN amplitudes[51] were observed in young heavy drinkers compared with non-heavy drinkers. These inconsistent findings seem to result from differences in the tasks used to measure error-monitoring across studies. For example, Smith et al.[51] used the Go/NoGo task to measure error-monitoring and found no significant differences in ERN amplitudes between heavy drinkers and non-heavy drinkers. Although various tasks are used to evaluate error-monitoring, different results are produced depending on the tasks used. For example, Riesel et al.[79] administered the Flanker, Stroop, and Go/NoGo tasks to measure error-monitoring ability in the same participants and found that the Stroop task produced more errors and smaller ERN amplitudes than the other two tasks. Inconsistent findings also seem to result from differences in participants' behavioral performance across studies. For example, Smith et al.[20] used the Flanker task to measure error-monitoring, and found enhanced ERN amplitudes in young female heavy drinkers. The authors suggested that enhanced ERN amplitudes reflect enhanced performance monitoring by heavy drinkers to achieve the same behavioral outcomes as the controls. In the present study, however, female college students with BD exhibited significantly more errors on the Flanker task compared with those with non-BD.

The BD and non-BD groups exhibited no significant differences in Pe amplitude and associations between Pe amplitudes and the scores on the AUDIT-K or AUQ were not observed. Previous studies with heavy drinkers re-

ported inconsistent results regarding to Pe amplitudes. For example, some studies found no differences in Pe amplitudes between heavy drinkers and non-heavy drinkers,[22,51] whereas others observed smaller Pe amplitudes in heavy drinkers than non-heavy drinkers.[49] As Pe amplitude is larger for perceived errors than for unperceived errors,[45,46] Pe is believed to reflect conscious error recognition. The comparable Pe amplitudes in the BD and non-BD groups indicate that college students with BD recognized their errors in the same way as those who did not participate in BD. Individuals who BD could perceive and recognize their erroneous responses, because the Flanker task which requires fast responding has the advantage of eliciting errors by slips rather than by mistakes resulting from misunderstanding the task.[80]

This study had some limitations that should be addressed in future studies. First, only a small number of participants included in the present study limits generalizability of the findings. Second, to better understand the neurophysiological mechanisms of error-monitoring deficits experienced by individuals with BD, both neuro-imaging techniques and ERPs should be used, because the structural abnormalities and dysfunctions in the ACC are observed in individuals with BD and those who drink heavily. Finally, BD college students are more likely to use other substances, including cigarettes and marijuana,[81] so these substances should be controlled for in future studies.

In conclusion, female BD college students exhibited significantly more errors and faster response times on the Flanker task and reduced ERN amplitude compared with those who did not participate in BD. Moreover, the ERN amplitudes measured at FCz and Cz were positively correlated with BD severity. These findings indicate that individuals with BD experience deficits in error-monitoring and self-control, and might give some explanations why individuals with BD continue alcohol consumption in spite of its associated negative consequences. Furthermore, present findings indicate that reduced ERN amplitudes may serve as a biological marker or risk factor for AUD. The present results also provide valuable information about detrimental effects of BD on cognitive and brain functions, even though the period of excessive alcohol consumption is relatively short (mean year of alcohol consumption in the BD group was 3.05 years).

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