Auditory-induced emotion modulates processes of response inhibition: an event-related potential study

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This study investigated the impact of auditory-induced emotion on response inhibition. Fifty kinds of positive, neutral, and negative sounds were used as emotional materials whose presentation was followed by a Go/Nogo task. Event-related potentials were recorded for Go and Nogo tones. The response times for Go stimuli were longer under negative than under positive and neutral emotions. In addition, Go and Nogo stimuli elicited larger N1 amplitudes during neutral than during emotional conditions. Moreover, Nogo-related N2 was larger for neutral sounds than for positive and negative sounds. The Nogo-N2, however, was not different between positive and negative sounds. Therefore, auditory-induced emotions significantly modulated the behavioral performance and the process of response conflict monitoring, a central component to the activity of response inhibition. ***NeuroReport*** **20:25–30 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

As a central element of executive function, the ability to withhold inappropriate responses plays an important role in individuals' adaptation to the fast changing environment [1]. In experimental settings, the early processes, such as sensory processing and the monitoring of response conflicts, form the basis for the achievement of this inhibition. Considerable event-related potential (ERP) studies consistently reported several components that characterize temporal features of response inhibition. Noteworthy, the frontal–central N2 and central–parietal P3, the two successive components that are typically elicited by Nogo stimuli in Go/Nogo task, are widely accepted as indexing conflict monitoring and response inhibition, respectively [2,3]. Orbitofrontal and inferior anterior cingulate cortices (ACC), the two regions that were indicated to be closely associated with behavioral inhibitory control [4,5], were considered to mediate the generation of N2 and P3 activity during response inhibition tasks.

As is known, emotion usually interacts with cognition, and mood fluctuations may influence individuals' ability to inhibit inappropriate responses in life settings [6,7]. For instance, aggression is closely related to negative emotion, whereas cognitive regulations often modulate the intensity of one's emotional experience for a given event [8]. Therefore, the normal functioning of a behavioral system involves not only the coordination between response execution and inhibition, but also the bidirectional modulation of emotion and inhibitory control [7,9]. The symptoms of psychiatric patients with behavioral dyscontrol (e.g. borderline or antisocial personality disorders) would be worse in negative emotional context [10]. Recently, the neural mechanisms underlying the interaction of emotion and response inhibition have been investigated extensively. Stadler *et al.* [11] observed reduced ACC activations in aggressive children during the presentation of negative pictures, suggesting an important role of ACC in the interaction of emotion and response inhibition. In addition, using functional magnetic resonance imaging measures, Goldstein *et al.* [7] revealed increased activations in medial orbitofrontal and amygdala during the inhibition of a response to emotional versus neutral adjectives. Furthermore, Shafritz *et al.* [12] found that the suppression of a habitual response to emotional faces significantly activated regions including medial prefrontal cortex and insula.

Nevertheless, the majority of these studies used emotional visual stimuli as experimental materials. In fact, auditory sensation plays an important role in the fast acquisition of emotional information, and in the adaptive living of organisms in the changing environment [13]. For instance, orienting response, whose happening is often associated with emotional reactions, are frequently elicited by auditory unpredictable stimuli [13]. It was reported that electrodermal reactions were larger for emotional than for neutral auditory stimuli, and that listening to unpleasant sounds resulted in larger startle reflexes, more electromyographic activity, and larger heart rate deceleration compared with listening to pleasant sounds [14,15]. Recently, it was shown that music of different emotional valence had different impact on brain activations and music functions importantly in the mental and behavioral therapies [16,17]. Nevertheless, how does the emotion elicited by auditory stimuli interact with response inhibition has yet to be directly investigated. It remains unknown whether the effect of emotion on response inhibition in auditory modality has some different features compared with that in vision.

Using ERP measures and an auditory Go/Nogo task, this study investigated the temporal features of the modulation effects of auditory emotions on response inhibition by using emotional sounds as experimental materials [2,3]. It was hypothesized that auditory-induced emotions significantly modulate processes of response inhibition, which may be manifested by the early effect of emotion on N2 that was widely accepted as reflecting response conflict monitoring [1,2]. In more detail, it is likely to observe an interaction effect between task type (Go/ Nogo) and emotion during N2 interval. The Nogo/Go difference ERPs at N2 interval, which behave as an index for the early effect of inhibitory processing [1], may vary in magnitude according to the emotional background formed by the sound stimuli [3]. Similarly, there might be an interaction effect of task type (Nogo vs. Go) and emotion on P3 amplitudes given the observation of an effect of emotion on late process of inhibitory control.

Methods

Participants

As paid volunteers, 15 college students (9 women, 6 men) aged 19–25 years (mean age, 21.8 years) participated in the experiment. All participants were healthy, right-handed, had normal or corrected-to-normal vision. All participants signed an informed consent form for the experiment. The experimental procedure was in accordance with the ethical principles of the 1964 Declaration of Helsinki.

Stimuli and experiment procedure

This study used a Go/Nogo task. A block design method was adopted for emotional inducement. According to the valence of the emotional context, the experiment was divided into three blocks: positive, neural, and negative. Therefore, the sound stimuli used in each block shared the same valence and induced a single kind of emotion. The sequence of the three blocks was counterbalanced across participants. Each block had 240 trials, including 72 Nogo and 168 Go stimuli (30 vs. 70%). Two tones of 1400 and 400 Hz served as Go and Nogo stimuli, respectively. The onset sequence of the Go and Nogo tones was randomized for each participant. Moreover, the assignment of tones for Go and Nogo signals was counterbalanced between participants. Before the presentation of Go or Nogo tones, an emotional sound was presented for 5 s to form an affective context. The 150 positive, neutral, and negative sounds were selected from Chinese Affective Sound System and Cox System [18,19]. Thirty additional volunteers who did not participate in the ERP experiment were recruited to reevaluate the valence and arousal of each emotional sound. The one-way analysis of variance (ANOVA) (valence and arousal as factors) showed a significant valence effect, $F(2,153) = 1467.8$, P value of less than 0.001. Post-hoc test showed that the averaged valence of positive sounds (7.07 ± 0.48) was higher than that of neutral sounds (4.97 ± 0.31). In turn, the valence of neutral sounds was higher than that of negative sounds (2.48 ± 0.48). Conversely, the arousal values of the three valence conditions were not significantly different.

Participants were seated in an acoustically isolated room at approximately 100 cm from computer screen. Before the experiment, participants were told that the experiment investigated their ability to withhold a habitual response to the frequent tone when the infrequent tone appeared. Each trial was initiated by a 250-ms presentation of a small black cross on the silver computer screen. Then, the presentation of the emotional sound that lasted for 5000 ms was followed by the onset of the stimulus tone. The stimulus tone was terminated by a key pressing or when it elapsed for 300 ms. Therefore, participants were informed that their responses must be as quick as possible. Each response was followed by a blank screen the duration of which varied from 1200 to 1500 ms. Pretraining with 10 practice trials was used before the experiment to familiarize participants with the procedure. The participants who achieved at least 80% accuracy during practice were then allowed to participate in the subsequent experiment. At the end of each block, participants assessed their subjective affective feelings by filling in the Positive Affect and Negative Affect Schedule [20]. In an interview session conducted immediately after the experiment, each participant was debriefed with respect to their performance during the task, in particular, with regard to their feelings about the response suppression for Nogo stimuli.

Event-related potential recording and analysis

Electroencephalography (EEG) was recorded from 64 scalp sites using tin electrodes mounted on an elastic cap (Neuro Scan, Sterling, Virginia, USA), with the references on the left and right mastoids and a ground electrode on the medial frontal aspect. Vertical electro oculograms (EOGs) were recorded supraorbitally and infraorbitally at the left eye. Horizontal EOG was recorded as the left versus right orbital rim. EEG and EOG activity was amplified with a DC 100 Hz bandpass and continuously sampled at 500 Hz/channel. All electrode impedances were maintained below 5 kΩ. An automated eye-movement correction program was used before artifact rejection. ERP averages were computed off-line. Trials with remaining EOG artifacts (mean EOG voltage exceeding ±80 mV), amplifier clipping artifacts, or peak-to-peak deflection exceeding ±80 mV were excluded from averaging. EEG activity for correct response during either condition was overlapped and averaged separately. ERP waveforms were time locked to the onset of tone stimuli, and the average epoch was 1200 ms, including a 200-ms prestimulus baseline. The following 18 electrode sites were selected for statistical analysis: F3, FC3, C3, CP3, P3, PO3, Fz, FCz, Cz, CPz, Pz, POz, F4, FC4, C4, CP4, P4, and PO4. First, to see whether there was an effect of emotion on early auditory processing, the N1 component, which peaked approximately 110 ms after stimulus onset, was measured and analyzed at 80–150 ms.

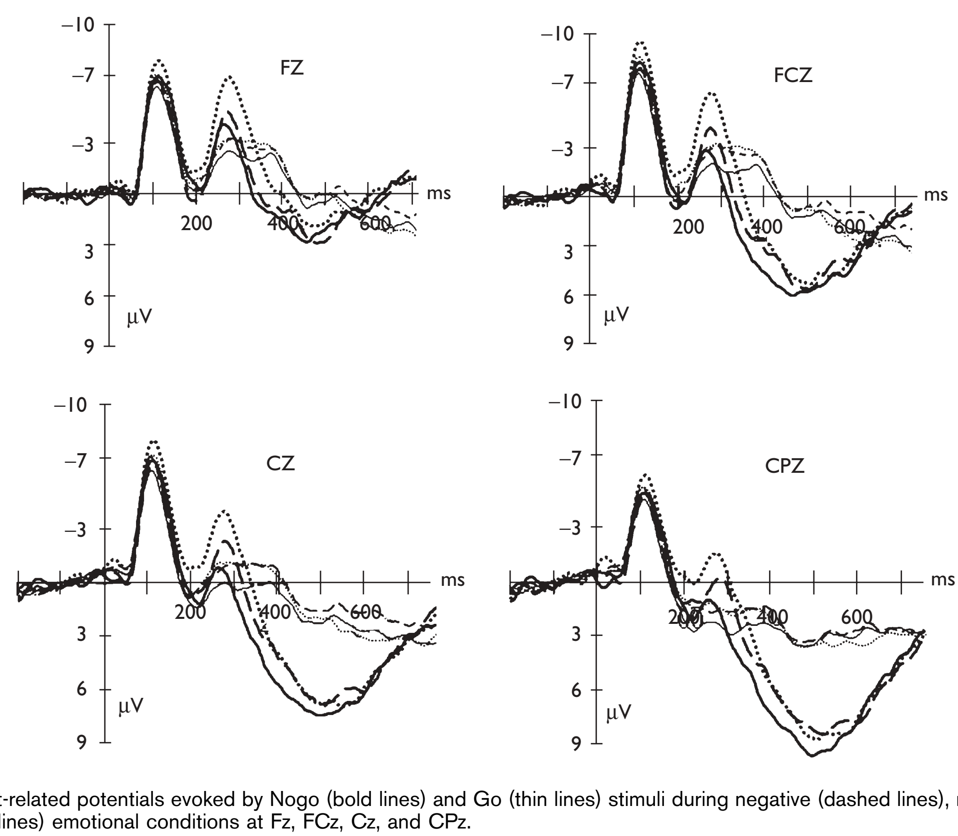
More importantly, as shown by Fig. 1, amplitude differences between Go and Nogo conditions started approximately at 200 ms across the three valence conditions. These differences were manifested by an N2 at 200–400 ms, and a P3 at 400–600 ms in the Nogo–Go difference wave that purely indexes processes of response inhibition. As this study investigated the effect of emotional inducement on processes of response inhibition, we focused on task type (Go, Nogo) and valence (negative, neutral, and positive) interaction effects for the averaged amplitudes at N2 and P3 intervals by conducting repeated-measures ANOVA. On the basis of significant task type and valence interaction effects, we further measured and analyzed peak latencies and amplitudes (baseline to peak) of these components at corresponding intervals. Repeated-measures ANOVAs would be conducted on the latencies and amplitudes of these components with electrode sites (18 sites), valence, and task type as repeated factors. The degrees of freedom of the *F*-ratio were corrected according to the Greenhouse–Geisser method in all these analyses.

Result

Self-reports by Positive Affect and Negative Affect Schedule

The repeated-measures ANOVA on the scores in the positive subscale showed a significant effect of emotion ($F = 12.516$, $P < 0.001$; $M_{neg} = 20.533$, $M_{neu} = 24.067$, $M_{pos} = 29.600$). The post-hoc analyses showed higher scores during positive than during negative ($P < 0.001$) and neutral ($P < 0.05$) conditions. The ANOVA on the scores in the negative subscale showed a significant emotion effect [$F = 41.738$, $P < 0.001$($M_{neg} = 27.733$, $M_{neu} = 17.000$, $M_{pos} = 14.000$)]. The post-hoc test showed higher scores during negative than during neutral conditions ($P < 0.001$).

Fig. 1



The averaged event-related potentials evoked by Nogo (bold lines) and Go (thin lines) stimuli during negative (dashed lines), neutral (dotted lines), and positive (solid lines) emotional conditions at Fz, FCz, Cz, and CPz.

The scores of neutral condition, in turn, were higher than those of positive condition ($P < 0.05$). Therefore, each block in the experiment was effective in the inducement of the corresponding emotion.

Behavior results

False responses are rare, as each participant achieved over 99% accuracy rates for both Go and Nogo conditions. The mean reaction times for Go stimuli are shown in Table 1. The repeated-measures ANOVA on Go response times showed a marginal emotional effect ($F = 3.005$, $P < 0.08$). The Go response times were significantly longer during negative condition than during neutral ($P < 0.05$) and positive ($P < 0.04$) conditions. Despite a tendency to be smaller, the Go response times of the positive condition were not significantly different from those of the neutral condition.

Event-related potential analysis

Original event-related potentials

The repeated-measures ANOVA on peak amplitudes of N1 showed a marginal effect of valence [$F(2,28) = 3.62$, $P = 0.05$] and a significant main effect of electrode site [$F(5,70) = 101.56$, $P < 0.001$]. The N1 amplitudes, irrespective of the task type, were larger during neutral than during emotional conditions. In contrast, the amplitude differences between negative and positive conditions were not significant. The amplitudes were largest across frontocentral areas. No other main or interaction effects were found at this component (Fig. 1).

Moreover, the ANOVA on the averaged amplitudes at 200–400 ms interval showed significant main effects of task [$F(1,14) = 59.69$, $P < 0.001$], valence [$F(2,28) = 7.56$, $P = 0.003$], and electrode sites [$F(2,28) = 21.29$, $P < 0.001$]. The amplitudes, which were largest at centrofrontal sites, were more pronounced during Nogo ($-3.15 \pm 0.91\,\mu V$) than during Go tasks ($0.85 \pm 0.60\,\mu V$). In addition, the amplitudes were larger during neutral condition than during emotional conditions. More importantly, the interaction effect of valence and task was significant [$F(2,28) = 4.05$, $P < 0.05$]. The simple effects analyses of the valence and task interaction effect revealed that the amplitude differences between Nogo and Go tasks were larger during neutral than during emotional conditions.

Finally, the statistical analysis of the averaged amplitudes at 400–600 ms interval revealed significant main effects of task type [$F(1,14) = 17.05$, $P = 0.001$] and electrode sites [$F(17,238) = 12.12$, $P < 0.001$]. P3 amplitudes, in particular those of Nogo P3, were largest at centroparietal sites. No other main or interaction effects were observed at this interval.

Table 1 Averaged reaction times for Go stimuli and the accuracy rates for Go and Nogo tasks under each emotional condition (M ± SD)

	Negative	Neutral	Positive
Go RTs (ms)	528.9 ± 112.1	502.8 ± 100.5	493.0 ± 89.8
Go ACC (%)	99.5 ± 0.7	99.6 ± 0.5	99.7 ± 0.5
Nogo ACC (%)	99.5 ± 0.6	99.5 ± 0.5	99.6 ± 0.6

ACC, accuracy rate; RT, reaction time.

Nogo–Go difference event-related potentials

Therefore, the interaction effect between task and valence was significant on the amplitudes at N2 interval. The repeated-measures ANOVA on N2 amplitudes of the Nogo–Go difference wave revealed a significant main effect of valence [$F(2,28) = 6.24$, $P < 0.01$]. Post-hoc test showed that the N2 amplitude was significantly larger during neutral than during negative and positive emotional conditions [$P < 0.05$, $P < 0.001$]. Nevertheless, the differences between negative and positive conditions failed to reach significance. In addition, the main effect of electrode sites was significant [$F = 9.546$, $P < 0.01$]. N2 amplitudes were larger in the right versus left sites [$F(2,28) = 9.55$, $P < 0.01$]. The repeated-measures ANOVA on N2 latencies found no significant main or interaction effects (Fig. 2).

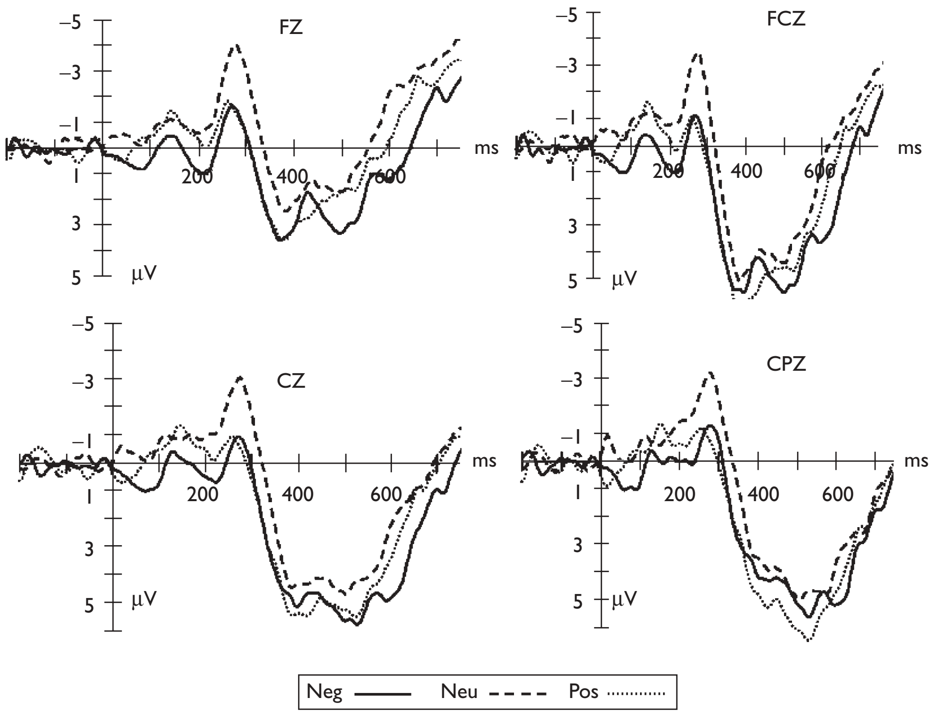
Discussion

Using an emotional Go/Nogo task, this study successfully induced expected emotions by affective sounds and observed significant effects of response inhibition at several processing stages, irrespective of the emotional context. This agrees with earlier reports that music, which is typical of emotional sounds, plays an important role in psychotherapy and behavioral treatment [17]. In addition, the ERP activity indicative of processes of response inhibition varies according to the emotional context. Obviously, as indicated by the response time data, auditory-induced emotion significantly influenced the participants' performance during the task. The Go response times were longer under negative emotion than under positive and neutral emotions, which agreed with earlier observations that response latencies for Go stimuli were longer with negative than with positive emotions [21,22].

At the 80–150 ms interval, a prominent frontal N1 reflecting early auditory processing was observed in both Go and Nogo tasks [23]. This was consistent with the observations by Woods [9]. The present experiment observed that the amplitude of N1 was influenced by emotional context. N1 amplitude, irrespective of the task type, was larger in neutral condition than in positive and negative conditions. Positive and negative conditions, however, showed no significant differences from each other. This suggests that the early auditory processing, as indexed by N1 activity, was modulated by emotional background, and that the influence of emotion on the processes of response inhibition may occur at later processing stages [23].

This study observed a significant main effect of task type during N2 and P3 intervals. Nogo stimuli elicited

Fig. 2



The difference event-related potentials of Nogo minus Go tasks during negative (solid lines), neutral (dashed lines), and positive (dotted lines) emotional conditions at Fz, FCz, Cz, and CPz.

increased N2 activity, and larger P3 amplitudes than did Go stimuli at corresponding intervals. These differences were manifested by a prominent N2 and a P3 component in the Nogo–Go difference wave. This indicates that the present auditory Go/Nogo task, similar to visual Go/Nogo tasks [2,5], elicited significant effects of response inhibition [2]. As frontal–central N2 elicited during inhibitory control tasks is accepted as an index for the detection of response conflicts [1,5,24] whereas the later response inhibition was suggested to modulate P3 amplitudes [2], the processes of response inhibition were mainly embodied by the effects at these two components in this study.

Moreover, this study observed a significant interaction effect of valence and task type on the averaged amplitudes at 200–400 ms interval, suggesting that the emotional context significantly modulated the early process of response inhibition. To expound the features of this interaction, we focused our analysis on the difference ERPs of Nogo minus Go conditions. As indicated by Fig. 2, the subtraction of ERPs elicited by Go stimuli from those elicited by Nogo stimuli generated a clear Nogo-related N2 component during 200–400 ms interval. The amplitudes of Nogo-related N2 amplitudes were significantly larger during neutral condition than during the emotional conditions. As is known, the increased N2 activity elicited by Nogo stimuli during the Go/Nogo task, which typically occurs at 200–400 ms interval, was accepted as an index for the detection of response conflicts, and for the increased attentional engagement that forms the basis for the subsequent process of inhibition [1]. Therefore, in this study, the early process of response conflict detection, as well as the corresponding attentional engagement, was significantly modulated by the emotional context. It is well established that emotional events are often processed preferentially or automatically as compared with neutral events [23,25]. Therefore, with the effective inducement of particular emotions, the psychological processing of the response conflicts evoked by Nogo stimuli, and the attentional engagement for this process, were likely to be attenuated during emotional conditions because the brain automatically diverted attention to the emotional information. Consequently, the amplitudes of Nogo-related N2 were largest under the neutral context that is free of emotional loads.

Interestingly, despite a significant effect of response inhibition during P3 stage, the processing of response inhibition was not significantly modulated by the emotional inducement. As described above, Nogo stimuli elicited larger positive deflections compared with Go stimuli at 400–600 ms poststimulus, whereas the interaction effect between task type and valence failed to reach significance. This suggests that the effect of emotion on processes of response inhibition was manifested mainly by the significant modulation effect of emotion on the early monitoring of response conflicts in this study. The absence of the task and valence interaction effect during P3 stage may result from the high engagement of participants in the auditory Go/Nogo task. This was consistent with several studies that observed similar effects of inhibitory control across valence conditions during a two-choice oddball task [23,25]. In these studies, being engaged in the frequent/infrequent distinction, participants responded similarly to infrequent stimuli under different valence conditions, despite the need to control for the prepotent response to frequent stimuli. Similarly, in this study, participants were highly engaged in the Go/Nogo task, as indexed by the high accuracy rates for both Go and Nogo stimuli across participants (Table 1). Therefore, the late process of inhibitory control was not significantly modulated by the auditory emotions, despite a significant effect of emotional inducement on the early monitoring of response conflicts. This hypothesis, of course, requires further investigation by manipulating the attentional load of the task in future studies.

Conclusion

In addition to conspicuous effects of response inhibition at several processing stages, this study observed that auditory-induced emotions significantly modulated one's performance during a response inhibition task. This was clearly manifested by the modulation effect of auditory emotions on the response latencies for Go stimuli, and on the early monitoring of response conflicts. Therefore, similar to the findings in visual studies, auditory induced emotions have a significant modulation effect on individuals' activity of response inhibition.

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