



Sex differences in electrophysiological indices of conflict monitoring

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ABSTRACT

The purpose of this study was to investigate sex differences in cognitive control as measured by the stimulus-locked N2 component of the event-related potential (ERP). High-density ERPs were obtained from 114 healthy individuals (60 females, 54 males) who completed a modified Eriksen Flanker Task. Behavioral measures (i.e., error rates, reaction times) and N2 amplitudes were analyzed. On the flanker task, females responded significantly slower and committed more errors than males. For N2 amplitude, there was a significant main effect of congruency, with increased amplitude to incongruent trials. Importantly, sexes differed as a function of congruency, with males showing significantly larger incongruent N2 amplitudes than females. Sex differences in N2 amplitude remained in a subgroup of participants that did not differ for behavioral, demographic, and affective variables. No sex differences were shown for electrophysiological or behavioral indices of conflict adaptation. Results indicate sex differences in brain activation associated with conflict monitoring. Findings may be explained by two contradictory possibilities: (1) females more effectively monitor conflict as indicated by less neural activation than males for similar behavioral performance in a matched subsample, or, (2) females less effectively monitor conflict than males.

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1. Introduction

The ability to recruit, engage, and modulate cognitive resources to monitor and regulate task-related behavior is an important part of healthy cognitive and behavioral functioning (Botvinick et al., 2001; Folstein and Van Petten, 2008; van Veen and Carter, 2002a; Yeung et al., 2004; Yeung and Cohen, 2006). Central to these processes is the ability to monitor and adapt to conflict. Conflict occurs when information from multiple stimuli or responses overlap or recruit identical neural pathways, disrupting parallel information processing. Such conflict is common during dual-task performance or when task-irrelevant and task-relevant information compete for attentional control (Botvinick et al., 2001). Due to limited capacity of the information processing system, the increased attentional demand associated with conflict necessitates the activation of compensatory mechanisms to enhance cognitive efficiency. Conflict monitoring is thought to increase attentional control by evaluating contextually relevant information for conflict and subsequently signaling for increased cognitive resources to reduce the effects of the conflict (Botvinick et al., 2001; Botvinick et al., 2004; Folstein and Van Petten, 2008; McLoughlin et al., 2009; Yeung and Cohen, 2006).

A growing body of literature shows sex differences in behavioral manifestations of conflict monitoring, specifically in the processing of task-irrelevant information (Bayliss et al., 2005; Garcia-Garcia et al., 2008; Li et al., 2006, 2009; Stoet, 2010). For example, females attended to irrelevant visual cues more than males in a Flanker-type task (Bayliss et al., 2005), and females were more distracted by novel auditory-visual stimuli in a negative emotional context than males (Garcia-Garcia et al., 2008). Building on these studies, Stoet (2010) examined sex differences in the processing of irrelevant information in a sample of 80 individuals (40 males, 40 females) using a novel GO/NOGO and Flanker task combination. During the task, a red, green, or blue flanker circle appeared in a grid followed by a central target circle. Participants were instructed to respond if the target stimulus was green or withhold a response if the target stimulus was red. The irrelevant flanker circles created conflict, as blue flankers were response-neutral and red or green flankers were either response-compatible if they matched the target or response-incompatible if they differed from the target. Females had slower response times (RTs) for incongruent trials and made more errors on go and no-go trials than males, possibly indicating that females were more distracted by high-conflict incompatible flankers than males, significantly slowing their performance (Stoet, 2010). Altogether, these studies suggest that females attend to irrelevant stimuli more than males, potentially demonstrating differential conflict monitoring.

One way to examine the neural underpinnings of conflict-related processing is through the conflict N2, a stimulus-locked

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fronto-central negative deflection of the scalp-recorded event-related potential (ERP) that is thought to reflect conflict monitoring processes (Botvinick et al., 2001). N2 amplitude is larger following high-conflict than low-conflict stimuli and is attenuated after increased attentional control (Albrecht et al., 2008; Dickter and Bartholow, 2010; van Veen and Carter, 2002b; Yeung and Cohen, 2006). Indeed, N2 latencies are closely related to RTs, suggesting that the N2 may index the duration of the response selection process (Gajewski et al., 2008). Source localization studies indicate the anterior cingulate cortex (ACC) is the neural generator of the N2 (Ladouceur et al., 2007; Ridderinkhof et al., 2004; van Veen and Carter, 2002a,b; Yeung et al., 2004). Several studies also indicate that negative affect influences conflict N2 amplitude (Durstun et al., 2003; Righi et al., 2009; Sehlmeier et al., 2010). For example, larger conflict N2 amplitudes correlate with high levels of trait anxiety (Righi et al., 2009; Sehlmeier et al., 2010); however, both larger and smaller conflict N2 amplitudes have been associated with high levels of depression (Bruder et al., 1998; Durstun et al., 2003; Iv et al., 2010; Ogura et al., 1993; Ruchow et al., 2008).

The Eriksen Flanker Task (Eriksen and Eriksen, 1974) is frequently used to elicit a conflict N2 due to the activation of competing response options (Dickter and Bartholow, 2010). In this task, participants respond to the direction of a central stimulus arrow. During congruent trials flanker stimuli cue a response similar to the target arrow (>>>>). During incongruent trials, flanker stimuli activate competing response options by prompting a response opposite the target arrow (>><<>>). N2 amplitude is larger during high-conflict trials when participants attend more to flanker stimuli vs. low-conflict trials when participants may be less distracted by flanker stimuli, indicating greater awareness of conflict between task-irrelevant (e.g., flankers) and task-relevant (e.g., target arrow) information (Danielmeier et al., 2009; Dickter and Bartholow, 2010; Folstein and Van Petten, 2008; Ullsperger et al., 2005; van Veen and Carter, 2002a,b; Yeung et al., 2004; Yeung and Cohen, 2006; Yeung et al., 2007).

N2 amplitude may also reflect conflict adaptation processes, or increases in cognitive and attentional control associated with previous-trial congruency. Conflict adaptation is based on the finding that performance differences may be sensitive to variations in control states associated with increased allocation of cognitive resources following high conflict trials (Botvinick et al., 2001; Forster et al., 2011; Gratton et al., 1992; Kerns, 2006; Kerns et al., 2004; Larson et al., 2009a). In the context of the conflict monitoring theory, detection of high conflict on incongruent trials should lead to the recruitment of more attentional control and cognitive resources to enhance performance (i.e., faster RTs, improved error rates, and decreased susceptibility to irrelevant stimulus information) on the subsequent trial (Botvinick et al., 2001, 2004; Carter and van Veen, 2007). Following a congruent trial, cognitive control is reduced, resulting in longer RTs, decreased error rates, and more processing of irrelevant stimulus information. Recently, Forster et al. (2011) demonstrated that N2 difference waves were larger for incongruent trials preceded by congruent trials (resulting in slower RTs) than incongruent trials preceded by incongruent trials (resulting in faster RTs). Thus, N2 amplitude may reflect neural activity associated with increased attentional control in response to conflict.

Due to the hypothesized role of the ACC in conflict N2 generation (Ridderinkhof et al., 2004) and recent literature revealing sex differences in putative markers of ACC activation (Larson et al., 2011; Li et al., 2006, 2009), the purpose of this study was to investigate sex differences in cognitive control as measured by the conflict N2. The findings of Stoet (2010) point toward sex differences in selective attention, suggesting that females may attend more to incompatible flankers. Based on this information, we hypothesized that females would exhibit larger conflict N2 amplitudes than males

during a modified Eriksen Flanker Task. Furthermore, we sought to clarify potential sex differences in conflict monitoring by investigating strategic adjustments in cognitive control associated with conflict adaptation.

2. Methods

2.1. Participants

All participants provided written informed consent as approved by the local Institutional Review Board. Participants were recruited from undergraduate psychology courses. Exclusion criteria, assessed via participant self-report, included current or previous diagnosis of a psychiatric or neurologic disorder, head injury, psychoactive medication use, substance use or dependence, left-handedness, or uncorrected visual impairment. Initial study enrollment included 121 individuals. Seven participants were excluded due to artifact from excessive muscle activity or due to technical problems. Final study enrollment, therefore, included 114 individuals (60 females, 54 males) between the ages of 18 and 30 ($M=20.96$, $SD=2.51$). Descriptive information for study participants is presented in Table 1.

2.2. Measures

Given the aforementioned relationships between anxiety and depression and N2 amplitudes (Durstun et al., 2003; Righi et al., 2009; Sehlmeier et al., 2010; Vanderhasselt and De Raedt, 2009), all participants completed the Beck Depression Inventory (2nd ed.; BDI-II; Beck, 1996) to measure levels of depressive symptoms and the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983) to measure levels of state and trait anxiety. Females demonstrated generally higher levels of depressive symptoms, state anxiety, and trait anxiety compared to males (see Table 1).

2.3. Experimental task

Participants completed a modified version of the Eriksen Flanker Task (Eriksen and Eriksen, 1974). Each trial consisted of either congruent or incongruent arrow stimuli presented in white on a black background of a computer monitor approximately 50.8 cm from the participant's head. Participants were instructed to respond as quickly and accurately as possible with a right-hand key press. An index-finger button press was used if the middle arrow pointed to the left and a middle-finger button press was used if the middle arrow pointed to the right. Flanker stimuli were presented for 100 ms prior to the onset of the target stimulus, which remained on the screen for 600 ms. The response window was 1600 ms. If the participant responded after 1600 ms, the trial was counted as an error of omission. The inter-trial interval (ITI) varied randomly between 800 ms, 1000 ms, and 1200 ms, with a mean ITI of 1000 ms. Three blocks of 300 trials (900 total trials) were presented; the distribution of congruent and incongruent trials was equal (450 trials each). Participants completed 24 practice trials prior to beginning the experimental task.

2.4. Electrophysiological data recording and reduction

Electroencephalogram (EEG) was recorded from 128 scalp sites using a geodesic sensor net and Electrical Geodesics, Inc. (EGI; Eugene, OR) amplifier system (20K nominal gain, bandpass = .10–100 Hz). Electroencephalogram was initially referenced to the vertex electrode and digitized continuously at 250 Hz with a 24-bit analog-to-digital converter. Consistent with guidelines recommended by the manufacturer, impedances were maintained below 50 k Ω . Data were average-referenced and digitally low-pass filtered at 30 Hz. Eye movement and blink artifacts were corrected using the algorithm described by Gratton et al. (1983).

Individual subject correct-trial N2 data were segmented spanning 150 ms prior to stimulus presentation to 500 ms after stimulus presentation. Epochs were baseline corrected using a 100 ms window from 150 ms to 50 ms before stimulus presentation. When a high-density EEG system is available, a region-of-interest (ROI) approach, where multiple electrodes at the site of interest are averaged together, provides increased reliability estimates of the ERP relative to single sensors (e.g., Larson et al., 2010). Thus, we used an ROI approach where sites were chosen based on the scalp distributions of the current data and previous research demonstrating that the N2 is focal over the fronto-medial locations (Danielmeier et al., 2009; Nieuwenhuis et al., 2003). Correct-trial congruent and incongruent amplitudes for the N2 were extracted as the average of 15 ms pre-peak to 15 ms post-peak negative amplitude between 270 ms and 380 ms and averaged across four fronto-central electrode sites (numbers 6 [FCz], 7, 106, and Ref [Cz]; see Fig. 1). Latency measurements for the N2 were extracted as the peak negative-going amplitude averaged across the abovementioned electrode sites within 270 ms and 380 ms following stimulus presentation.

In order to assess conflict adaptation effects, individual N2 segments were derived based on four possible variations of current- and previous-trial congruencies: a congruent trial preceded by a congruent trial (cC), a congruent trial preceded by an incongruent trial (iC), an incongruent trial preceded by an incongruent trial (ii), and an incongruent trial preceded by a congruent trial (ci). Separate stimulus-locked

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