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Fluid intelligence and neural mechanisms of conflict adaptation

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ABSTRACT

The current study investigated whether adolescents with different intellectual levels have different conflict adaptation processes. Adolescents with high and average IQ abilities were enrolled, and their behavioral responses and event-related potentials (ERPs) were recorded during a modified Eriksen flanker task. Both groups showed reliable conflict adaptation effects (CAE) with regard to the reaction time (RT), and they showed a faster response to the cC condition than to the iC condition and faster response to the iI condition than to the cI condition. The IQ-related findings showed that high IQ adolescents had shorter RTs than their average-IQ counterparts in the cI, iC, and iI conditions, with smaller *RT-CAE* values. These findings indicated that high IQ adolescents had superior conflict adaptation processes. The electrophysiological findings showed that the cI condition required more conflict monitoring processes than the cC condition through the induction of more negative N450 responses. With regard to the adaptation control processes, high IQ adolescents showed greater slow potential (SP) amplitudes than their average IQ peers in the iI condition; furthermore, they showed better adaptation control processing with smaller *SP amplitude-CAE* values. In conclusion, the present study revealed the essential association between fluid intelligence and conflict adaptation processes.

1. Introduction

Human fluid intelligence exists since an individual's birth and is not influenced by acquired knowledge (Sternberg, 1985). It relates to flexible coping and better adaptive behaviors in response to the changing environment (Johnson, 2013). Individuals with higher intellectual levels exhibit better cognitive control and self-regulation behaviors than those with average intellectual levels (Arffa, 2007; Calero, García-Martín, Jiménez, Kazén, & Araque, 2007; Johnson, Im-Bolter, & Pascual-Leone, 2003; Liu, Xiao, Shi, & Zhao, 2011a; Liu, Xiao, Shi, Zhao, & Liu, 2011b; Schweizer & Moosbrugger, 2004). The brains of individuals with a higher fluid intelligence are considered to function more efficiently (Chalke & Ertl, 1965); furthermore, these individuals can use their brain circuits and neurons more efficiently for accomplishing advanced cognitive tasks according to the neural efficiency hypothesis of intelligence (Neubauer & Fink, 2009a,b).

Conflict adaptation is associated with conflict-driven sequential modulation and reflects an individual's adaptation abilities (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Clayson & Larson, 2011a,b; Egner, 2007; Ullsperger, Bylsma, & Botvinick, 2005). Conflict adaptation processes include the sub-processes of monitoring the current conflict situation, resolving the conflict, and preparing appropriately for the subsequent adjustments (Hommel, Proctor, & Vu, 2004; Mayr & Awh, 2009; Mayr, Awh, & Laurey, 2003; Verguts & Notebaert, 2008). The conflict adaptation effect (CAE) was first explored by Gratton, Coles & Donchin (1992) using a flanker paradigm (the congruent stimuli [C]: >>>>>, <<<<<; the incongruent stimuli [I]: >><>>, <<><<). Four conflict adaptation conditions are further categorized according to the congruency between the preceding trial and the current trial: the preceding congruent trial [c]—the current congruent trial [C] [cC condition], the preceding congruent trial [c]—the current incongruent trial [I] [cI condition], the preceding incongruent trial [i]—the current congruent trial [C] [iC condition], and the preceding incongruent trial [i]—the current incongruent trial [I] [iI condition]. CAE describes the phenomena whereby individuals exhibit faster and more accurate responses in the iI condition than in the cI condition and in the cC condition than in the iC condition (see Egner, 2007, for review; Gratton et al., 1992; Kerns, 2006; Kerns et al., 2004; Liu, Chen, Li, Li, & West, 2012; Ullsperger et al., 2005). The reaction time-related CAE (*RT-CAE*) can be calculated using Eq. (1), and the lower *RT-CAE* values reflect better conflict adaptation abilities (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Nieuwenhuis et al., 2006; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Tang, Hu, Li, Zhang, & Chen, 2013).

$$RT\text{-}CAE = (RT_{cI} - RT_{cC}) - (RT_{iI} - RT_{iC}) \tag{1}$$

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Furthermore, electrophysiological studies have revealed that two event-related potential (ERP) components are associated with the neural correlates of conflict adaptation processes: the N450 and conflict-sensitive slow potential (conflict SP) components. The N450 component, with a neural distribution in the frontal area particularly the anterior cingulate cortex (ACC), relates to conflict monitoring processes (Liotti et al., 2000; Sheth et al., 2012; West, 2003), and smaller N450 amplitudes and shorter N450 latencies reflect better conflict monitoring processes (Larson, Farrer, & Clayson, 2011; Larson, Kaufman, & Perlstein, 2009 a,b; Liotti, Woldorff, Perez, & Mayberg, 2000; Tang et al., 2013; van Veen & Carter, 2002; West & Alain, 1999; West, Bowry, & McConville, 2004). Meanwhile, the SP component, with a neural distribution in the parietal area, is associated with adaptation control processes on conflicts (Mansouri, Tanaka, & Buckley, 2009; Sheth et al., 2012; West et al., 2004; Zysset, Müller, Lohmann, & von Cramon, 2001), with incongruent trials eliciting larger conflict SP amplitudes than congruent trials (Larson et al., 2009a, 2011; Liotti et al., 2000; Perlstein, Larson, Dotson, & Kelly, 2006; Tang et al., 2013; West, 2003; West & Alain, 1999; West, Jakubek, Wymbs, Perry, & Moore, 2005). Moreover, previous electrophysiological studies have shown that intellectually gifted children exhibit more efficient and better neural responses with regard to conflict monitoring and attentional control than their average IQ counterparts (Liu et al., 2011a,b). The ERP-related CAE (*ERP-CAE*), with the peak amplitudes of N450 (*N450-CAE*) and SP (*SP-CAE*), can be measured using Eq. (2), with lower *ERP-CAE* values reflecting better neural conflict adaptation processes (Botvinick et al., 1999; Nieuwenhuis et al., 2006; Stürmer et al., 2002; Tang et al., 2013):

$$ERP - CAE = (ERP_{cI} - ERP_{cC}) - (ERP_{iI} - ERP_{iC}) \tag{2}$$

The aim of the present study was to investigate whether individuals with different intellectual abilities showed different neural dynamic activities during conflict adaptation processes. Adolescence is an extremely important period for the neurodevelopment of intellectual and cognitive abilities, and an adolescent's adaptation abilities to the complex and changing environment have a long-lasting influence on his/her development over the lifetime (Blakemore & Choudhury, 2006; Burnett, Sebastian, Kadosh, & Blakemore, 2011; Casey, Duhoux, & Cohen, 2010; Kadosh, Linden, & Lau, 2013; Larson, Clawson, Clayson, & South, 2012; Pfeifer et al., 2011; Somerville, Jones, & Casey, 2010). Therefore, we enrolled two groups of adolescents (a high IQ group and an average IQ group) and compared their conflict adaptation processes to test the following hypotheses: (1) high IQ adolescents show better conflict adaptation behaviors (greater accuracy and shorter RT) and neural responses (shorter ERP latencies and larger SP amplitudes) than average IQ adolescents; (2) both groups show significant CAEs (significant interactions between preceding trial and current trial); and (3) high IQ adolescents show lower *RT-CAE*, *N450-CAE*, and *SP-CAE* values than their average IQ counterparts.

2. Material and methods

2.1. Participants

Two groups of adolescents participated in the current study. Adolescents with a high IQ ($n = 22$, 12 boys and 10 girls; ages range, 13.2–14 years; mean age, 13.5 years) were recruited from a gifted education system known as the Gifted Youth Class, which offers a curriculum emphasizing scientific domains, such as, mathematics, physics, chemistry, and biology. The Gifted Youth Class enrolls 30 children from approximately 2000 candidates each year according to multiple criteria and methods. The main steps for enrollment identification include the following: an application, a primary screening test (several classical intelligence tests), a retest (assessment of several cognitive abilities [attention, memory, and executive function], personality traits [motivation], and creativity), and behavioral observation under the same educational environment. The children's physical conditions and learning abilities are also confirmed. Adolescents with an average IQ ($n = 22$, 11 boys and 11 girls; age range, 13.3–14.1 years; mean age, 13.6 years) were selected from a normal middle school. All participants were right-handed with normal or corrected-to-normal visual acuity, and none had psychiatric or neurological problems. Written informed consent for participation was obtained from all parents.

The fluid intelligence of participants was assessed by administering two intelligence tests: the Cattell's Culture Faire Test (55 items; 1 point/item; scale range, 0–55) and the Raven's Standard Progressive Matrices (60 items; 1 point/item; scale range, 0–60) (Cattell, 1963; Raven, Court, & Raven, 1977). The mean (standard deviation, SD) score in the Raven test was 55.36 (2.06) for the high IQ group and 45.36 (2.87) for the average IQ group, while that in the Cattell test was 51.21 (1.85) for the high IQ group and 40.32 (3.69) for the average IQ group. Intergroup differences were calculated using *t*-tests and Cohen's *d*, with the high IQ group achieving significantly higher intelligence scores than the average IQ group in both intelligence tests [Cattell Test: $t(42) = 12.44$, $p < 0.001$, Cohen's $d = 3.82$; Raven test: $t(42) = 13.27$, $p < 0.001$, Cohen's $d = 4.11$].

2.2. Stimuli and procedure

The current study modified the Eriksen flanker task for the investigation of conflict adaptation processes (Eriksen & Eriksen, 1974; Gratton et al., 1992). Each stimulus presentation contained five black arrows on the white monitor background with a central target arrow and four flanker arrows (two on the bilateral sides of the central arrow), and the visual angles of the stimulus were 4° vertically and 7° horizontally. The stimulus presentations >>>> > and <<<<< were congruent stimuli (C), while > > <> > and <<> < < were incongruent stimuli (I). Participants were required to press the response buttons with their left or right index finger according to the direction indicated by the central arrow. Each trial began with a central fixation "+" (400 ms), followed by the stimulus presentation (1000 ms) and a blank screen. The intertrial interval (ITI) was 800 ms. In the practice block, 24 trials were displayed for each participant to familiarize with the experimental procedure and response rules. In the formal experiment, three blocks including 720 trials in total were displayed, with 324 congruent trials and 396 incongruent trials. Participants were encouraged to rest for 3–5 min after each block. The entire experiment lasted for approximately 40 min.

2.3. Electroencephalogram (EEG) recording and data preanalysis

EEGs were recorded from a Neuroscan cap with 64 scalp electrodes, with the electrode positions in accordance with the extended 10–20 system locations. Two electrodes places inferior and superior to the left eye and two bipolar electrodes placed at the outer canthi of each eye monitored the vertical and horizontal electrooculograms (VEOG and HEOG), respectively. The skin resistance of each electrode was adjusted to less than 5 kΩ. The EEG signal was continuously recorded at a sample rate of 500 Hz using the nose as a reference, and it was amplified using SynAmps amplifiers with an online band-pass filter at 0.05–100 Hz. We epoched the EEG signal with 100 ms before and 1000 ms after stimulus presentation, and a prestimulus interval of 100 ms was used for baseline correction. ERPs were subjected to offline Zero Phase Shift digital filtering (bandwidth, 1–30 Hz; slope, 24 dB/octave). Prior to averaging, all epochs were screened for eye blinks and other artifacts, and epochs contaminated by eye movements, or muscle potentials exceeding $\pm 70\ \mu V$ at any channel were excluded from the averaging process. Overall, less than 10% epochs were excluded from further analyses, and only correct trials were averaged into ERPs.

According to previous studies and the current data, electrophysiological analysis of the N450 component was focused on a time window of 500–650 ms over the frontal and central regions (average for the electrodes at F3, F1, Fz, F2, F4, F6, FC3, FC1, FCz, FC2, FC4, C3, C1, Cz, C2, and