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Neural correlates of cognitive style and flexible cognitive control

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ABSTRACT

Human abilities of flexible cognitive control are associated with appropriately regulating the amount of cognitive control required in response to contextual demands. In the context of conflicting situations, for instance, the amount of cognitive control increases according to the level of previously experienced conflict, resulting in optimized performance. We explored whether the amount of cognitive control in conflict resolution was related to individual differences in cognitive style that were determined with the Object–Spatial–Verbal cognitive style questionnaire. In this functional magnetic resonance imaging (fMRI) study, a version of the color–word Stroop task, which evokes conflict between color and verbal components, was employed to explore whether individual preferences for distracting information were related to the increases in neural conflict adaptation in cognitive control network regions. The behavioral data revealed that the more the verbal style was preferred, the greater the conflict adaptation effect was observed, especially when the current trial type was congruent. Consistent with the behavioral data, the imaging results demonstrated increased neural conflict adaptation effects in task-relevant network regions, including the left dorsolateral prefrontal cortex, left fusiform gyrus, and left precuneus, as the preference for verbal style increased. These results provide new evidence that flexible cognitive control is closely associated with individuals' preference of cognitive style.

Introduction

Humans employ control systems that integrate thought and action in order to adjust our behaviors to environmental demands to achieve our internal goals. This ability is referred to as cognitive control (Miller and Cohen, 2001). The conflict monitoring theory, which is a predominant account of cognitive control, explains how the amount of cognitive control is adjusted in response to transient levels of conflict (Botvinick et al., 2001, 2004). For example, in the Stroop task (Stroop, 1935), performance in incongruent trials (e.g., "RED" printed in green ink) is slower than that in congruent trials (e.g., "GREEN" printed in green ink). In this task, reaction times (RTs) are faster for incongruent trials following incongruent trials (iI) than those following congruent trials (cI) and slower for congruent trials following incongruent trials (iC) than those following congruent trials (cC), and this is referred to as the conflict adaptation effect (Gratton et al., 1992). According to the conflict monitoring theory, the conflict adaptation effect indicates that the level of cognitive control is higher in iI trials than in cI trials and in iC trials than in cC trials due to temporary upregulation of control, which is composed of the monitor-controller system (Botvinick et al., 1999; Kerns et al., 2004). Consistently, neuroimaging studies have found a dissociation of the anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DLPFC) in the roles of conflict monitoring and resolution, respectively (Botvinick et al., 2001, 2004; MacDonald et al., 2000).

With respect to individual differences in conflict adaptation, previous studies have correlated conflict adaptation effects with age (Kray et al., 2012; Larson et al., 2012), working memory capacity (Soutschek et al., 2013; Weldon et al., 2013), and emotion (Padmala et al., 2011; van Steenbergen et al., 2010). These studies have focused on the relationship between conflict adaptation and other cognitive abilities or the differences between groups that are distinguished by biological features, such as age and gender. However, other studies on the relationship between cognitive style and modality-specific information processes have suggested that cognitive style could also be related to individual differences in conflict resolution between different modality-specific information processes (Alloway et al., 2010; Blazhenkova and Kozhevnikov, 2009; Kolloffel, 2012; Kozhevnikov et al., 2010; Kraemer et al., 2009; Riding and Agrell, 1997).

One of the most widely used cognitive styles is the Visual–Verbal style. Previous studies have regarded Visual–Verbal cognitive style as a bipolar unitary construction (Pavio, 1971; Richardson, 1977). However, the Object–Spatial imagery and Verbal cognitive style model has been suggested based on a body of literature that has revealed a dissociation between object and spatial imagery (Blajenkova et al., 2006; Blazhenkova and Kozhevnikov, 2009; Kozhevnikov et al., 2010; Ungerleider and Haxby, 1994). According to this model, object style is defined by the preference for colorful, detailed, and pictorial information, while spatial style

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is characterized by the preference for object location, movement, and spatial relationships. Verbal style describes the consistent use of verbal processing.

The aim of the present study was to investigate the relationship between cognitive style and conflict adaptation. In doing so, we manipulated a version of the color–word Stroop task, which evokes conflict, as subjects were required to focus on color information while ignoring verbal information. It could be assumed that, especially in incongruent trials, those who prefer verbal style would recruit greater amount of cognitive control compared to those who prefer object style because of their different preferences between color and verbal processes. Based on this, we expected that greater conflict adaptation and Stroop effects would be observed as the preference for the verbal style increased. More importantly, thus, the neural activation associated with cognitive control would increase as a function of the preference for the verbal style. More specifically, if the cognitive style shows relationships with both ACC and DLPFC, this would show that cognitive style has an influence on both conflict detection and regulation. In contrast, if the relationship is observed with only ACC or DLPFC, this would indicate that cognitive style exerts an influence on either the monitoring or resolving processes in flexible cognitive control.

Methods

Subjects

Forty-three healthy young adult subjects (20 females) between the ages of 18 and 28 (mean (M), 21.5, standard deviation (SD), 2.49) participated in this study. All of the subjects were right-handed native Korean speakers with normal or corrected-to-normal vision without color blindness. None had any history of psychiatric or neurological disease. All of the subjects provided written informed consents on forms approved by the Brain Science Research Center at KAIST in Daejeon, South Korea.

Materials and procedures

Experimental task programming, stimulus presentation, and the recording of behavioral responses were conducted with E-Prime 2.0. For the behavioral task, a version of the color–word Stroop task was used to measure conflict adaptation effects. The task stimuli, which consisted of a sample word and two response probes (see Fig. 1), were presented on a black background. The sample word was a color name that was presented in one of six different colors (red, yellow, blue, green, orange, or purple). The response probes, which were the color names of those above colors, were presented in white. In the congruent (CON) trials, the sample consisted of a corresponding color and word (e.g., “RED” printed in red ink). In the incongruent (INC) trials, in contrast, the color and word of the sample were inconsistent with each other (e.g., “GREEN” printed in blue ink). For the response probes, one was the correct answer, which indicated the color of the sample, and the other worked as a nontarget distracter. For the CON trials, the distracting probe was randomly selected from the spellings of five colors that were not used in the sample. For the INC trials, the distracting probe was the same word as the sample (e.g., for “RED” printed in blue ink, the correct probe was “BLUE” and the distracting probe was “RED”). The color names used for the sample and the response probes were presented in Korean.

Subjects were required to select the correct response probe corresponding to the color of the sample and not to the word of the sample. In order to measure the conflict adaptation effect, the experimental conditions were composed of preceding trial congruency (CON and INC) and current trial congruency (CON and INC), resulting in four types of conditions: CON-CON (cC), CON-INC (cI), INC-CON (iC), and INC-INC (iI). Forty trials for each condition were included in the task and presented in a pseudorandomly intermixed order. It has been noted that controlling for additional factors, such as the repetition priming effect (Mayr et al., 2003), is important for measuring the conflict adaptation effect. In doing so, the stimuli for the sample and the response probes were changed from trial to trial. Thus, neither the same colors nor the same words were presented in two consecutive trials.

The task consisted of two sessions and 80 trials were included in each session. Stimuli were presented for 1000 ms, and the intertrial interval (ITI) was varied from 1000 ms to 5000 ms (mean ITI, 3000 ms). Before starting the functional magnetic resonance imaging (fMRI) experiment, participants performed a practice session containing five trials for each condition (i.e., a total of 20 trials). During the fMRI experiment, behavioral responses were recorded by pressing the left or right button that corresponded to the side of the correct response probe with either the left or right thumb. The participants were asked to respond to each trial as quickly and accurately as possible.

After providing consent to participate in the study, the participants were administered the Korean version of the Object–Spatial–Verbal cognitive style questionnaire (OSIVQ: Blazhenkova and Kozhevnikov, 2009; Shin and Kim, 2013). OSIVQ was developed to measure individual differences in the preference for the object, spatial, and verbal cognitive styles. For instance, a statement, such as, “I have a photographic memory,” was used to assess the preference for object style and was answered with the 5-point Likert scale.

Imaging acquisition

fMRI data were acquired with a 3-T Siemens Verio scanner (the fMRI Center at KAIST, Daejeon, South Korea). T2*-weighted gradient echo planner images (EPI) that were composed of 33 interleaved slices were acquired for the functional image [repetition time (TR), 2000 ms; echo

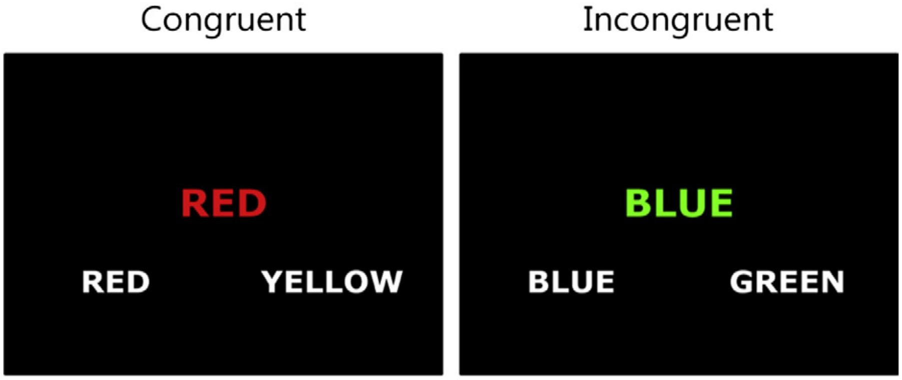

Fig. 1. Task stimuli and conditions used in the functional magnetic resonance imaging (fMRI) experiment. The task required subjects to identify the color of the sample (e.g., green for the word “BLUE”) and to respond to the correct response probe word that spelled the color. Four different conditions, including congruent (CON)–CON (cC), CON–incongruent (INC) (cI), INC–CON (iC), and INC–INC (iI), were presented in randomized order during the task.