NeuroImage 66 (2013) 577–584

Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

The neural mechanisms of semantic and response conflicts: An fMRI study of practice-related effects in the Stroop task

Zhencai Chen [a,1], Xu Lei [a,1], Cody Ding [a,b], Hong Li [c], Antao Chen [a,c,*]

[a] Key Laboratory of Cognition and Personality (Ministry of Education) and School of Psychology, Southwest University, Chongqing, China
[b] Department of Educational Psychology, Research, and Evaluation, University of Missouri-St. Louis, St. Louis, MO, USA
[c] Research Center of Psychological Development and Education, Liaoning Normal University, Dalian, Liaoning, China

ARTICLE INFO

Article history:
Accepted 19 October 2012
Available online 24 October 2012

Keywords:
Stroop task
Semantic conflict
Response conflict
Practice effects
fMRI

ABSTRACT

Previous studies have demonstrated that there are separate neural mechanisms underlying semantic and response conflicts in the Stroop task. However, the practice effects of these conflicts need to be elucidated and the possible involvements of common neural mechanisms are yet to be established. We employed functional magnetic resonance imaging (fMRI) in a 4–2 mapping practice-related Stroop task to determine the neural substrates under these conflicts. Results showed that different patterns of brain activations are associated with practice in the attentional networks (e.g., dorsolateral prefrontal cortex (DLPFC), anterior cingulate cortex (ACC), and posterior parietal cortex (PPC)) for both conflicts, response control regions (e.g., inferior frontal junction (IFJ), inferior frontal gyrus (IFG)/insula, and pre-supplementary motor areas (pre-SMA)) for semantic conflict, and posterior cortex for response conflict. We also found areas of common activation in the left hemisphere within the attentional networks, for the early practice stage in semantic conflict and the late stage in "pure" response conflict using conjunction analysis. The different practice effects indicate that there are distinct mechanisms underlying these two conflict types: semantic conflict practice effects are attributable to the automation of stimulus processing, conflict and response control; response conflict practice effects are attributable to the proportional increase of conflict-related cognitive resources. In addition, the areas of common activation suggest that the semantic conflict effect may contain a partial response conflict effect, particularly at the beginning of the task. These findings indicate that there are two kinds of response conflicts contained in the key-pressing Stroop task: the vocal-level (mainly in the early stage) and key-pressing (mainly in the late stage) response conflicts; thus, the use of the subtraction method for the exploration of semantic and response conflicts may need to be further examined.

Introduction

Conflict control tasks such as the Stroop, Flanker and Simon tasks have long been used to research human cognitive control functions (Eriksen and Eriksen, 1974; Simon and Small, 1969; Stroop, 1935). Cognitive control is a key process of flexible behavior. It helps us move toward our goals, especially in conflict situations, through the setting and maintaining of goals, the inhibition of inappropriate responses, and/or the amplification of target-relevant responses during behavioral execution (Aron, 2007; Egner and Hirsch, 2005; Miller, 2000; Ridderinkhof et al., 2004b).

The brain regions most frequently associated with cognitive control are the top-down frontal cortex networks, including the dorsolateral prefrontal cortex (DLPFC), and anterior cingulate cortex (ACC), and the response organization regions, including the posterior parietal cortex (PPC), supplementary motor areas (SMA), and pre-supplementary motor areas (pre-SMA) (Aron, 2011; Banich et al., 2000; Wang et al., 2010). The DLPFC is an integrative system; it receives and represents information from other cortical structures and initiates top-down biases based on task demands (Brass et al., 2005a,b; Mansouri et al., 2009; Miller and Cohen, 2001). The ACC is responsible for conflict monitoring, and emotion- or motivation-related cognitive control operations (Botvinick et al., 2001, 2004; Carter and van Veen, 2007; Ridderinkhof et al., 2004a). The PPC modulates attentional orientation to task-relevant information and prepares the stimulus–response (S–R) mapping (Coulthard et al., 2008; Scherberger and Andersen, 2007). The SMA and pre-SMA are considered to play a role in the selection and execution of responses (Lau et al., 2006; Nachev et al., 2008; Rushworth et al., 2007).

Experiments that focus on the practice-related effects of the Stroop task are important for elucidating the mechanisms of the Stroop task and cognitive control (MacLeod, 1991). In the Stroop task, inked color words are presented to subjects, who are instructed to response to the color of word while ignore its meaning. Regardless of whether the word and color are congruent (e.g. "red" in red) or

* Corresponding author at: Key Laboratory of Cognition and Personality (Ministry of Education) and School of Psychology, Southwest University, Chongqing, 400715, China.
E-mail address: xscat@swu.edu.cn (A. Chen).
[1] Zhencai Chen and Xu Lei contributed equally to this work.

1053-8119/$ – see front matter © 2012 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.neuroimage.2012.10.028

incongruent (e.g. "red" in green), the word reading tends to be automatically processed with higher priority over the color naming, which is also the task-relevant task. The transferring from the early stage of practice to the late stage of practice in the Stroop task is associated with the reduction of this discrepancy through the reinforcement of color naming pathways and changes in brain activity (Cohen et al., 1990; Davidson et al., 2003; Polk et al., 2008), which may involve quantitative functional change, qualitative reorganization, or even the reorganization of cognitive control brain networks (Jonides, 2004; Kelly and Garavan, 2005; Schumacher et al., 2005). Thus, examining the practice effects can help us to understand the role of specific brain areas in a dynamic way.

Erickson and colleagues studied the practice effects associated with cognitive control using the Stroop task. They found a dramatic decrease in ACC activity and an increase in DLPFC activation when the first half of the trials were compared with the second half of trials (Erickson et al., 2004; Milham et al., 2002). However, employment of traditional Stroop paradigm prevented them from separating semantic and response conflicts during the practice of the task. Thus, they were unable to determine whether the changes in brain activity were caused by the practice effects for semantic or response conflict, or both. In addition, their experiment was comprised of only 162 trials, markedly fewer trials than those used in other studies, which often consist of hundreds or thousands of practice trials (Dulaney and Rogers, 1994; Macleod, 1998). Erickson and colleagues did not observe practice effects at the behavioral level, which further suggests that the amount of practice was limited. As a result, the respective practice effects of semantic and response conflicts remain unclear.

In this study, we attempted to clarify this issue using different types of conflict and practice design. De Houwer (2003) was the first to identify the distinctions between semantic and response conflicts using the Stroop task. This was discovered via the logic of subtraction. The Stroop task comprises congruent (CO) stimuli (e.g., the word "red" in red), semantic incongruent (SI) stimuli, and response incongruent (RI) stimuli. Therefore, if red and yellow are mapped to the left hand, and blue and green are mapped to the right hand, the word "red" in yellow color (SI) is likely to provoke semantic conflict (of word reading and color naming), but responses are congruent; and the word "red" in blue color (RI) has both a semantic conflict and a conflict in response selection. Hence, SI-CO can produce a semantic conflict and RI-SI can prompt a response conflict (van Veen and Carter, 2005).

Previous research has successfully distinguished response conflict from semantic conflict. For instance, Kim et al. (2010) and van Veen and Carter (2005) revealed the parallel attentional control mechanisms underlying semantic and response conflicts using the Stroop task (Kim et al., 2010; van Veen and Carter, 2005). Likewise, Banich and colleagues were able to separate the response conflict by subtracting the effects of response-ineligible incongruent trials (e.g., the word "brown" in blue color, when red, blue are the set of potential responses) from the response-eligible incongruent trials (e.g., the word "red" in blue color, when red, blue are the set of potential responses). The semantic conflict was distinguished by contrasting the response-ineligible incongruent trials with the neutral trials (Liu et al., 2006; Milham et al., 2001, 2003a).

However, the study by van Veen and Carter (2005) revealed no overlap in activation between semantic and response conflicts using conjunction analysis. This appears to go against evidence from electrophysiological studies, which showed common activation in terms of N2 and N450 event-related potential (ERP) components (they are associated with the ACC activation in conflict detection) for both response and non-response conflict conditions (Wendt et al., 2007; West et al., 2004). Furthermore, Liu et al. (2004) found that the stimulus–stimulus conflict Stroop effects and stimulus–response conflict Simon effects had some common brain sources; both of them implicated the DLPFC top-down modulation of the posterior cortex (Liu et al., 2004). This indicates that semantic and response conflict types may both correlate with the common mechanisms underlying conflict monitoring and top-down conflict resolution processes.

In order to explore the common neural basis of semantic and response conflicts, we employed a novel strategy for the conjunction analysis. Since the stimulus–response mapping in the manual Stroop task (color to key-pressing) is usually weaker than that in the oral Stroop task (color to vocal response), the semantic conflict in our manual Stroop task may also include some components of the vocal-level response conflict (Gordon and Deborah, 1977; Repovš, 2004). We speculated that the effect of the early practice stage SI-CO would be eliminated after practice. Because the practice would reduce the vocal-level response conflict in SI stimuli due to the increased connection between key-pressing and color naming (S–R mapping) during the practice, which would also make the effects of RI-SI be "purer" in the late practice stage. Therefore, instead of directly testing the overlap in activation between these conflicts within the same practice stage, we examined the overlap between the early stage SI-CO condition and the late stage "pure" RI-SI condition to see whether the semantic conflict effect contained response conflict components or not.

Based on previous research investigating practice effects and attentional control, we anticipated that brain activity associated with semantic and response interference may appear as distinct distributions, and that many of the active areas will primarily belong to the attentional networks (e.g., the DLPFC, ACC and PCC) (Adleman et al., 2002; Kim et al., 2010; van Veen and Carter, 2005). The findings of Erickson et al. (2004) expressed a rapid decline in ACC activity and increased DLPFC activity in the incongruent condition after practice. According to the subtraction logic, the RI stimuli will prompt both semantic and response conflicts at the same time; the practice-related changes of RI stimuli might be caused by both the semantic and response conflict effects. Thus, in the current study, we anticipated that the SI-CO and/or RI-SI would be associated with a decrease in ACC activity and an increase in DLPFC activity after practice. In addition, based on our previous behavioral study (Chen et al., 2010), we expected that the practice effects of sematic conflict might be responsible for the decrease of activity in these areas, while the practice effects of response conflict might be responsible for the increase.

In summary, the present study was an attempt to address above unresolved issues related to cognitive control and examine the subtraction logic of the separateness for semantic and response conflicts, through the exploration of the respective practice effects and the common neural mechanisms of these two conflicts.

Materials and methods

Subjects

Twenty five right-handed college students, were recruited for the study with a compensation (15 females; M = 21, SD = 1.67). All participations had normal or corrected-to-normal vision, without achromatopsia or color weakness. The fMRI data of two subjects was excluded due to excessive head movement artifacts. This study was approved by the University Human Ethics Committee for the Brain Mapping Research, and written consent was obtained from each subject before scanning.

Stimuli

A 4–2 Stroop paradigm was employed using four Chinese characters "Hong" (red), "Huang" (yellow), "Lan" (blue) and "Lv" (green). Each character was presented in one of the four colors (i.e., red, yellow, blue and green; 16 stimuli altogether). Subjects were asked to respond according to the color of the characters; the red and yellow