Neural correlates of stimulus and response interference in a 2–1 mapping stroop task

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ABSTRACT

Two sources of interference (i.e., stimulus and response) are believed to contribute to the Stroop interference effect. Some neurophysiological evidence reveals that different neuro-cognitive processes are related to stimulus and response interference in the Stroop and related tasks. However, other evidence indicates that similar patterns of neural recruitment may be associated with these two types interference. Given these discrepant findings, the current study used a 2–1 mapping Stroop task in combination with event-related brain potentials (ERPs) to examine the neural correlates of stimulus and response interference. The response time data revealed that stimulus interference was constant across the response time distribution. In contrast, response interference increased in magnitude across the response time distribution for all but the slowest trials. The stimulus-locked ERP data revealed that early and later modulations of the medial frontal negativity may be sensitive to response interference, but not stimulus interference. These data also revealed that the conflict slow potential (SP) over the parietal and right lateral frontal regions was sensitive to both stimulus and response interference; in contrast, the conflict SP over the left lateral frontal region was only sensitive to response interference. Together the stimulus- and response-locked data lead to the conclusion that the parietal region is primarily involved in response selection in the Stroop task, and that the lateral frontal regions may participate in response monitoring and conflict adaption.

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1. Introduction

The Stroop task (Stroop, 1935) has been used extensively to examine the neural basis of conflict processing. In this task, individuals are asked to identify the color of a color-word where the association between the color and word varies over trials. For congruent trials the color and word are the same (e.g., RED presented in red); in contrast, for incongruent trials the color and word differ (e.g., RED presented in blue). Response time is generally slower for incongruent trials than for congruent trials, and this difference has been labeled the Stroop effect (MacLeod, 1991). Behavioral findings demonstrate that the Stroop effect arises from competition between the color and word at both stimulus (semantic) and response levels of information processing (Zhang and Kornblum, 1998; Milham et al., 2001; De Houwer, 2003; Schmidt and Cheesman, 2005; van Veen and Carter, 2005). Additionally, some evidence reveals that the processing or resolution of stimulus and response interference may be associated with differential neural recruitment (Milham et al., 2001; West et al., 2004; van Veen and Carter, 2005). The current study utilized a 2–1 mapping Stroop task (Zhang and Kornblum, 1998; De Houwer, 2003) in combination with behavioral and event-related potential (ERP) measures to examine similarities in and differences between the time

course and functional characteristics of neuro-cognitive processes associated with stimulus and response interference.

Studies using ERPs to examine the neural correlates of the Stroop effect have consistently revealed two modulations of the physiology that differentiate congruent (and neutral) trials from incongruent trials (Liotti et al., 2000; West, 2003; West and Alain, 2000). The medial frontal negativity (MFN) or N450 reflects greater negativity for incongruent trials than for congruent trials over the midline frontal–central region of the scalp between 300–500 ms after stimulus onset (Liotti et al., 2000; West and Alain, 2000). The label "MFN" may be more appropriate for this modulation of the ERPs than the "N450" used in earlier studies (West, 2003; West and Alain, 2000) as the timing of the effect of congruency over the frontal–central region can vary with the information processing demands of the task. There is some evidence that the MFN reflects two distinct modulations of the ERPs, an early modulation that is greater in amplitude over the left midline region and a later modulation that is greater in amplitude over the central midline region (Markela-Lerenc et al., 2004). The conflict slow potential (SP) reflects greater positivity for incongruent trials than for congruent trials over the parietal region and greater negativity for incongruent trials than for congruent trials over the lateral frontal regions between 500 and 1000+ ms after stimulus onset (Liotti et al., 2000; West and Alain, 2000). The MFN and conflict SP are elicited in a variety of Stoop-like tasks (West et al., 2005), indicating that these modulations of the ERPs are generally related to conflict processing.

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The MFN and conflict SP appear to reflect the recruitment of distinct processes that are related to conflict detection and response selection or conflict resolution in the Stroop and similar tasks. The amplitude of the MFN increases with the magnitude of the interference effect, while the timing of this modulation does not appear to be as sensitive to the magnitude of interference (West and Alain, 2000). This finding led to the suggestion that the MFN is associated with conflict detection rather than conflict resolution (West et al., 2005). Source modeling of the MFN reveals that it may arise from the activity of neural generators in the left frontal (early modulation; Markela-Lerenc et al., 2004) and medial frontal or anterior cingulate cortex (ACC, later modulation; Liotti et al., 2000; West, 2003). In contrast to the MFN, the amplitude and duration of the conflict SP increase with the magnitude of the interference effect (West and Alain, 2000; Roper et al., 2008). The amplitude of the conflict SP is correlated with response time for both congruent and incongruent trials (West et al., 2005). This finding has been taken to indicate that the conflict SP is generally associated with response selection rather than being specifically related to conflict resolution on incongruent trials (West et al., 2005). Additionally, one recent study (Bailey et al., 2010) found that over the left lateral frontal region of the scalp the conflict SP, or slow wave activity, persisted for several hundred milliseconds after the response. This finding led to the suggestion that the conflict SP over the left lateral frontal region is associated with processes related to adaptation of cognitive control settings across trials (Bailey et al., 2010). Source modeling of the conflict SP reveals that it may arise from the activity of neural generators in the lateral frontal and posterior cortex (West, 2003; Hanslmayr et al., 2008). The results of source modeling work related to the MFN and the conflict SP are consistent with the findings of studies using functional magnetic resonance imaging (fMRI) that consistently reveal greater activation in ACC, lateral prefrontal cortex, and posterior parietal cortex for incongruent trials relative to congruent trials (e.g., Carter et al., 2000; MacDonald et al., 2000; Milham et al., 2001; van Veen and Carter, 2005).

Two approaches have been used to examine the contribution of stimulus and response interference to the Stroop and flanker effects. One paradigm uses incongruent trials that are either incongruent-eligible (i.e., the irrelevant stimulus dimension is in the response set) or incongruent-ineligible (i.e., the irrelevant stimulus dimension is not in the response set; Milham et al., 2001; West et al., 2004). For instance, if the colors red and green were used in a manual response Stroop task, an incongruent-eligible stimulus would be RED presented in green, and an incongruent-ineligible stimulus would be BLUE presented in red since blue is not in the response set. Stimulus and response interference is thought to contribute to response time for incongruent-eligible trials, while only stimulus interference is thought to contribute to response time for incongruent-ineligible trials. In this task, response time tends to increase from congruent stimuli to incongruent-ineligible stimuli to incongruent-eligible stimuli, demonstrating the contribution of both stimulus and response interference to the Stroop effect. The second paradigm (i.e., 2–1 mapping task) uses two colors mapped to the same manual response to isolate the contribution of stimulus and response interference to the Stroop effect (Zhang and Kornblum, 1998; De Houwer, 2003). For instance, in a four color Stroop task two colors would be mapped to each of two response keys. Stimulus incongruent trials reflect stimuli where the color and word differ but are mapped to the same response, while response incongruent trials reflect stimuli where the color and word differ and are mapped to different responses. In this task, response time tends to increase from congruent stimuli to stimulus incongruent stimuli to response incongruent stimuli, again demonstrating the contribution of stimulus and response interference to the Stroop effect.

Studies using these paradigms to examine the neural correlates of stimulus and response interference incorporating ERPs have revealed

mixed results. In two studies using the counting Stroop task, West and colleagues (West et al., 2004; West and Schwarb, 2006) found that the MFN was elicited by both incongruent-ineligible and incongruent-eligible stimuli relative to congruent stimuli. These findings indicate that the medial frontal cortex may be sensitive to both stimulus and response interference. Additionally, the conflict SP was observed for both types of incongruent stimuli, with the conflict SP elicited by incongruent-eligible stimuli lasting longer than the conflict SP elicited by incongruent-ineligible stimuli. In contrast to the findings of West and colleagues, van Veen and Carter (2002) found that the MFN (frontocentral N2) was elicited by response incongruent stimuli and not by stimulus incongruent stimuli in a study using the 2–1 mapping paradigm with the flanker task. These findings may indicate that the eligibility and 2–1 mapping paradigms vary in the degree that the relevant task conditions allow one to clearly distinguish the influence of stimulus and response interference to the generation of the MFN and conflict SP. However, the 2–1 mapping task has not been used in combination with ERPs and Stroop stimuli so it is also possible that differences between the findings of West et al. and van Veen and Carter are related to variation in task demands between the Stroop task and the flanker task.

In the present study we used a 2–1 mapping Stroop task where six colors were mapped to three responses. If the MFN is sensitive to response interference and insensitive to stimulus interference (van Veen and Carter, 2002), we predicted that the amplitude of the MFN would be greater for response incongruent trials than for stimulus incongruent trials and congruent trials. If the conflict SP is generally related to response selection or conflict resolution (West et al., 2005), we predicted that the amplitude of this modulation of the ERPs would be greater for stimulus and response incongruent trials than for congruent trials. We also expected that the conflict SP would persist longer for response incongruent trials than for stimulus incongruent trials given the longer response time for the response incongruent trials and the finding that the conflict SP for incongruent-eligible trials extends in time beyond the conflict SP for incongruent-ineligible trials (West et al., 2004).

2. Method

2.1. Participants

Thirty-one undergraduates from Iowa State University (17 females; M = 19.9 years, range 17–27) participated in the experiment. All had normal or corrected-to-normal vision, and were naive to the purposes of the experiment. Based on responses to the Edinburgh Handedness Inventory (Oldfield, 1971), 25 were right handed, 5 were ambidextrous, and 1 was left handed. All participants provided informed consent, and the study was approved by the Human Subjects Institutional Review Board of the university. The participants received course credit for their participation.

2.2. Materials and procedure

The stimuli were the names of six colors (BLUE, GRAY, GREEN, WHITE, YELLOW, and PURPLE) presented in upper case letters. For the study, blue and gray were mapped to the B key and the right index finger, green and white were mapped to the N key and the right middle finger, and yellow and purple were mapped to the M key and the right ring finger. For each trial one of the color words was presented in one of the six colors. For congruent trials, the color and word matched (e.g., BLUE presented in blue); for stimulus incongruent trials the color and word differed but were mapped to the same response (e.g., GREEN presented in white); for response incongruent trials the color and word differed and were mapped to different responses (e.g., YELLOW presented in gray). Full counterbalancing of the colors and words across trial type results in six congruent stimuli,