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An electrophysiological correlate of conflict processing in an auditory spatial Stroop task: The effect of individual differences in navigational style

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ABSTRACT

Recent work has identified an event-related potential (ERP) component, the incongruency negativity (N_{inc}), which is sensitive to auditory Stroop conflict processing. Here, we investigated how this index of conflict processing is influenced by individual differences in cognitive style. There is evidence that individuals differ in the strategy they use to navigate through the environment; some use a predominantly verbal-egocentric strategy while others rely more heavily on a spatial-allocentric strategy. In addition, navigational strategy, assessed by a way-finding questionnaire, is predictive of performance on an auditory spatial Stroop task, in which either the semantic or spatial dimension of stimuli must be ignored. To explore the influence of individual differences in navigational style on conflict processing, participants took part in an auditory spatial Stroop task while the electroencephalogram (EEG) was recorded. Whereas behavioral performance only showed a main effect of congruency, we observed the predicted three-way interaction between congruency, task type and navigational style with respect to our physiological measure of Stroop conflict. Specifically, congruency-dependent modulation of the N_{inc} was observed only when participants performed their non-dominant task (e.g., verbal navigators attempting to ignore semantic information). These results confirm that the N_{inc} reliably indexes auditory Stroop conflict and extend previous results by demonstrating that the N_{inc} is predictably modulated by individual differences in cognitive style.

1. Introduction

How individuals process and respond to stimuli in the presence of irrelevant (and possibly conflicting) information is a central question within the field of cognitive neuroscience. Stroop (1935) first explored this question from a behavioral perspective, demonstrating that when the ink color and semantic meaning of a word are in conflict (e.g. the word "BLUE" written in red ink), participants take longer to identify the word's ink color. To date, many variations of this classic paradigm have been well studied within the visual modality; see MacLeod (1991) for a review. In addition, neuroimaging (Herd et al., 2006; MacLeod and MacDonald, 2000) and electrophysiological (Donohue et al., 2012; Duncan-Johnson and Kopell, 1981; Ila and Polich, 1999; Liotti et al., 2000; Rebai et al., 1997; West et al., 2005, 2012; West, 2003) techniques have helped to identify the neural correlates and time course of visual Stroop processing. Recent work by Donohue et al. (2012) has extended these findings to the auditory modality.

The connectionist model of Stroop conflict by Cohen et al. (1990) explains Stroop interference as arising from relative differences in how automatically a given stimulus dimension is processed. For example, in the traditional Stroop task, participants are required to identify the ink color of a word, while ignoring the word's semantic meaning. However, because lexical processing (attending to semantic information) is presumably an over-learned and automatic process, both the ink color (which is task-relevant) and the semantic meaning of the word (which is task-irrelevant) are processed in parallel; interference is thought to occur because additional processing is required to select one response from the two conflicting representations of the stimulus (Cohen et al., 1990; MacLeod, 1991; MacLeod and MacDonald, 2000). The major contribution of the Cohen et al. (1990) model was its ability to account for training studies (MacLeod and Dunbar, 1988), which show that participants can be trained in such a way as to reduce the relative automaticity of processing semantic aspects of a stimulus. That is, a strong conclusion of the Cohen et al. (1990) model is that the relative automaticity of processing semantic information can vary across contexts and possibly participants. However, the role or influence of individual differences has rarely been examined and remains unclear.

More recent work by Herd et al. (2006), guided by an emphasis on neural constraints, has expanded on the model by Cohen et al. (1990).

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Briefly, this model explains cognitive control within the Stroop task as arising from excitatory projections from prefrontal cortical areas to sensory regions associated with processing task-relevant information (e.g., ink color, in the traditional Stroop task). Similar to the biased competition model of attention by Desimone and Duncan (1995), this top-down excitation of the neuronal networks dedicated to encoding task-relevant information leads to competitive inhibition of cortical regions dedicated to processing task-irrelevant information (e.g., orthographic information, in the classic Stroop task) (Herd et al., 2006; Munakata et al., 2011). Failures of this biasing process are thought to lead to the instantiation and detection of conflict at a post-perceptual processing stage. The Anterior Cingulate Cortex (ACC) is believed to perform this conflict-monitoring function (Banich, 2009). Supporting this notion is electrophysiological work utilizing source localization to provide evidence that ACC activation increases in response to Stroop conflict (Liotti et al., 2000; West et al., 2012; West, 2003).

A growing body of research demonstrates that individuals tend to use one of two fundamentally different strategies when navigating through the environment (Baldwin and Reagan, 2009; Garden et al., 2001; Kato and Takeuchi, 2003; Lawton et al., 1996). While verbal navigators[1] tend to rely heavily on verbal working memory, encoding spatial relationships using semantic codes (e.g. "turn right, go straight, then turn left"), spatial navigators tend to rely on visuo-spatial working memory and encode the spatial world using an allocentric reference frame (i.e. a top-down map-like representation of the spatial world) (Baldwin and Reagan, 2009; Garden et al., 2001). As shown by Barrow and Baldwin (2010b) behavioral performance on an auditory spatial Stroop task (which involves evaluating spatial and semantic stimulus dimensions) is influenced by individual differences in navigational style. Whereas verbal navigators find it more difficult to ignore task-irrelevant semantic information, spatial navigators find it more difficult to ignore task-irrelevant spatial information. Thus, when an individual attempts to perform their non-dominant task (e.g. a verbal navigator attempting to ignore semantic information) increased Stroop interference is instantiated (Barrow and Baldwin, 2010b).

The top-down biasing model of Herd et al. (2006) and earlier work by Cohen et al. (1990) suggest that the influence of navigational style on performance in the auditory spatial Stroop task can be explained by individual differences in the automaticity of spatial or semantic processing. Due to longstanding activation of an individual's preferred stimulus dimension, one might expect Hebbian strengthening to enhance the neural representation of this stimulus dimension, even when it is task-irrelevant (Hebb, 1949). In line with this argument, Kraemer et al. (2009) have shown that individuals differing on the Verbalizer–Visualizer cognitive style assessment (Kirby et al., 1988) tend to show increased activation of regions dedicated to their preferred modality, even when it is not beneficial to the task. Similarly, Maeder et al. (2001) have shown that auditory localization and recognition tasks rely on distinct cortical regions and that individuals differ in their relative performance on these two tasks. In the case of the Stroop task, one might expect that although top-down control generates a bias towards the task-relevant stimulus dimension, this bias would be relatively weak as a result of the strength of the preexisting bias towards the task-irrelevant stimulus dimension. In this scenario, when individuals perform their non-dominant task, the similarly weighted representations of the two stimulus dimensions would be expected to produce increased response conflict and a corresponding increase in activation of conflict-monitoring processes.

Within the visual modality, Stroop interference can be detected by approximately 450 ms after stimulus onset, as indexed by two midline ERP components: the Medial Frontal Negativity (MFN), maximal at fronto-central electrode sites, and the Medial Posterior Negativity (MPN), maximal at posterior electrode sites (Liotti et al., 2000; West et al., 2012). Although the MPN differs from the MFN in that it has a slightly earlier onset and is observed only when a manual response is required (Liotti et al., 2000), both components are believed to reflect a common cognitive process. Specifically, these components have been interpreted as reflecting post-perceptual processing that emerges when conflicting motor commands compete at the response selection stage (Liotti et al., 2000; West et al., 2012). In addition, source localization studies suggest that this activity originates from the ACC (Liotti et al., 2000; West et al., 2012; West, 2003). Following these components, and emerging approximately 500 ms after stimulus onset, the sustained potential (SP), a positive slow wave maximal at posterior electrode sites, is observed. The SP is thought to reflect additional processing required to resolve the conflict between competing motor responses (West, 2003; but see West et al., 2005).

Donohue et al. (2012) have recently identified an auditory, congruency-dependent ERP component termed the incongruency negativity (N_{inc}), which is similar to the visual MFN/MPN. Although this component occurs approximately 150 ms earlier than the visual MFN/MPN, it exhibits similar response-dependent changes in scalp topography. When a manual response is required the N_{inc} has a parietal topography, whereas when a verbal response is required this component has a more frontal topography. The reason for the observed latency difference across modalities remains unclear, although it is possible that it is due in part to differences in sensory processing between the auditory and visual modalities (Hillyard, 1993). Consistent with this possibility, Donohue et al. (2012) propose that the MFN/MPN and N_{inc} reflect a single supramodal conflict monitoring process.

In the present study, both verbal and spatial navigators performed an auditory spatial Stroop task that required participants to attend to either the spatial location (the "location task") or semantic meaning (the "semantic task") of stimuli that sometimes conflicted in their spatial and semantic dimensions (e.g. the word "left" presented from a speaker positioned to the right). We hypothesized that individual differences in navigational style would be predictive of task performance, presumably due to differences in the automaticity of processing the semantic and spatial dimensions of the stimuli. In order to provide a neural correlate of conflict processing, we recorded event-related potentials (ERPs). We expected to observe a congruency-dependent modulation of the N_{inc} ERP component and predicted that this effect would be most pronounced for the non-dominant task for each type of navigator (the location task for verbal navigators and the semantic task for spatial navigators). In addition, we also evaluated the potential for the SP (West, 2003) to be modulated as a function of congruency, task type and navigational style.

2. Methods

2.1. Participants

Ninety-nine participants (57 females, M age = 21.92, SD = 6.08) were recruited from the George Mason University undergraduate population and provided course credit for their participation. Following identification of navigational style (described in Section 2.2.1) and rejection due to artifact contamination or poor performance (described in Section 2.4), nine spatial navigators (five females, M age = 22.22, SD = 6.85) and 13 verbal navigators (five females, M age = 21.85, SD = 5.15) remained for behavioral and ERP analyses. All participants had self-reported normal (or corrected to normal) hearing, spoke fluent English and had no known neurological deficits. All participants provided written informed consent after having been explained the procedures of the study. All procedures were approved by the Office of Research Subject Protections at George Mason University.

[1] It should be noted that Baldwin and Reagan (2009) classified individuals as having either a "good" or "poor" sense of direction (SOD). However, because "good" navigators tend to rely on visuo-spatial working memory while navigating and "poor" navigators tend to rely on verbal working while navigating, we refer to these individuals here as "verbal navigators" and "spatial navigators", respectively.