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Stroop interference and the timing of selective response activation

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ABSTRACT

Objective: To examine the exact timing of selective response activation in a manual color-word Stroop task.
Methods: Healthy individuals performed two versions of a manual color-word Stroop task, varying in the probability of incongruent color-words, while EEG was recorded.
Results: Stroop interference effect was manifested as longer reaction times for incongruent relative to congruent color-words, and was larger in a task version where incongruent color-words were presented less frequently. Whereas the congruence between color display and word meaning did not affect average stimulus- and response-locked lateralized readiness potential (LRP) onset latencies nor response-locked LRP amplitudes, P3 peak latencies were longer and stimulus-locked LRPs were smaller for incongruent than congruent trials.
Conclusions: These data are consistent with the idea that behavioral Stroop interference reflects delays in processing stages preceding color-based selective response activation in a subset of trials. They also do not exclude additional delays after color-based selective response activation, at least up until some 200 ms before the overt response.
Significance: This chronometric analysis allows for a parcellation of the Stroop interference process that may be applied in psychopathology.

1. Introduction

Interference between two incompatible response cues has been studied extensively using the Stroop task. In the Stroop paradigm, color-words printed in different ink colors are presented and participants are required to name the ink color of the color-word (Stroop, 1935). The Stroop interference effect is the longer time that it takes to name the ink color of a color-word when the ink color and printed color-word are incongruent (e.g., 'RED' in blue ink) as compared to congruent (e.g., 'RED' in red). Numerous theoretical accounts to explain the Stroop effect have been proposed (MacLeod, 1991). A very influential model of Stroop interference is based on the parallel distributed processing framework (Cohen et al., 1990). According to Cohen's model, information processing occurs through activation moving along pathways of varying strengths (Cohen et al., 1990). Different stimulus attributes are processed in parallel through different pathways. The relative strength of two competing pathways (e.g., one for color and one for word processing) determines the degree of Stroop interference. Attention and expectancies may influence the relative strength of a pathway. The model is relatively silent about the stage(s) of information processing in which word and color information interfere so as to produce reduced speed and accuracy. More recently, the dimensional overlap (DO) model has been developed to account for interference effects in various task paradigms, including the Stroop task (Zhang et al., 1999). This model holds that the Stroop interference effect reflects both stimulus conflict and response competition (Zhang et al., 1999). More specifically, overlap between two stimulus dimensions (SS-overlap) (ink color and color-word) at the stimulus processing stage may result in stimulus conflict, whereas overlap between stimulus dimension and response dimension (SR-overlap) at the response production stage may result in response competition. Note that response competition in this model depends on (1) the speed of identifying the correct response (controlled process), (2) the speed of stopping the incorrect response (stop automatic process), and (3) the degree of 'mutual inhibition' at the response output stage (Zhang et al., 1999). Consistent with the prediction of Zhang's model, results from a modified version of the Stroop task, in which word and color information in a stimulus are incongruent, but nevertheless map on the same hand response, indicated that Stroop interference reflects stimulus (i.e., semantic) as well response conflict (De Houwer, 2003; Schmidt and Cheesman, 2005; van Veen and Carter, 2005). This suggests that incongruency slows processing

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both in more perceptual (e.g., secondary sensory cortex) and in more response-related (e.g., motor cortex) stages.

The goal of this study was to examine the locus of Stroop interference using electrophysiological chronometric measures (P3 and lateralized readiness potential [LRP]). Button responses and peripheral measures of response activation, such as the EMG (electromyogram) response, can be used to assess whether people respond slower in one condition than in another (e.g., incongruent vs. congruent color-words). It can then be inferred that the duration of one or more processes has been affected. However, these measures do not provide us with direct information about whether these durations differ for early stages of stimulus processing or relatively late stages of motor responding. Event-related potentials (ERP) can be used to identify the mechanisms responsible for an observed behavioral effect, especially the P3 component and the lateralized readiness potential (LRP). It has been proposed that the P3 provides a measure of stimulus evaluation or identification (Kutas et al., 1977; Smulders et al., 1995). P3 latency may be thus used to determine whether an effect on RT originates from processes leading up to stimulus categorization or processes following stimulus categorization (Luck, 2005). The LRP is the later part of the readiness potential (RP) and is larger at scalp sites contralateral to a moved hand (e.g., De Jong et al., 1990; Gratton et al., 1988). It is obtained by comparing electroencephalographic (EEG) activity over the right and left motor cortices prior to the execution of a left or right hand movement. By definition, the LRP reflects hand-specific lateralized response activation. Therefore, it can be seen as a physiological measure of selective response activation for one hand over the other. LRPs may be used to elucidate whether an experimental manipulation affects stages of processing before or after the onset of hand-specific lateralized response activation. Theoretically, if a manipulation affects processes that precede selective response activation, the time interval between stimulus onset and LRP will be affected; if a manipulation affects processes after the start of selective response activation, the time interval between LRP onset and reaction time will be affected. To estimate the former time interval, signals are aligned to stimulus onset and averaged to obtain the stimulus-locked LRP (s-LRP), from which the interval between stimulus onset and LRP onset can be estimated. To estimate the latter time interval, signals are aligned to reaction time and averaged to obtain the response-locked LRP (r-LRP), from which the interval between LRP onset and reaction time can be estimated (Osman and Moore, 1993; Smulders et al., 1995).

Previous studies that investigated the locus of Stroop interference have examined the P3 component, but not LRP. It has consistently reported that longer reaction times for incongruent relative to congruent color-words were not associated with delayed P3 latencies, suggesting that the Stroop effect originates from response- rather than earlier stimulus-related processes (Atkinson et al., 2003; Duncan-Johnson and Kopell, 1981; Ilan and Polich, 1999; Rosenfeld and Skogsberg, 2006). However, the absence of a P3-latency effect still leaves open quite some room for clarification as to the exact mechanism and locus of Stroop interference, using movement-related brain potentials (i.e., LRP). Partly based on Zhang's DO model the following scenarios may be anticipated (see Fig. 1). First, word processing (automatic process) may on average be faster than color processing (controlled process), and the incorrect motor response may be prepared although the correct overt response will ultimately be given. This is reflected by an early dip in the LRP toward incorrect response activation on incongruent trials. Second, word and color processing are equal in average speed, and compete with each other before selective response activation starts, resulting in a delayed s-LRP-onset latency for incongruent stimuli. Third, color-based selective response activation may commence at the same average time point for congruent and incongruent stimuli, resulting in equal s-LRP onset latencies. Based on the concept of mutual inhibition at the response stage (Zhang et al., 1999), competition between the responses (word reading and color naming) may slow the build-up of correct color-based selective response activation. Consequently, the s-LRP will be equal in onset, but smaller in amplitude. A slower build-up of correct activation after LRP onset may not necessary result in longer intervals between the r-LRP and the overt response itself (i.e., r-LRP onset latency; as reported, in other contexts, by Osman and Moore (1993) and Smulders et al. (1995).

To be able to derive LRPs, this study used a manual Stroop task. Previous studies have revealed very much comparable, although perhaps somewhat smaller interference effects for manual relative to vocal versions of the Stroop test (MacLeod, 1991). In addition, it has been demonstrated that semantic conflict may also be present in a manual Stroop test (Brown and Besner, 2001). Moreover, very much comparable brain correlates of Stroop interference have been found in vocal and manual Stroop versions (see Liotti et al., 2000 for an ERP study; see Barch et al., 2001 for an fMRI study).

In this study, we manipulated the relative probabilities of congruent and incongruent Stroop stimuli. In a version of the Stroop task where there is a low expectancy of incongruent color-words, participants may develop a bias towards word reading (enhance strength of word processing pathway relative to strength of color processing pathway). Following the conflict-monitoring theory (Botvinick et al., 2001), in this situation, less tonic attentional control will be exerted over the tendency to read the color-word. Consequently, the level of conflict will be increased. In contrast, in a version of the Stroop task where there is high expectancy of incongruent color-words, the strength of the color processing pathway will increase and high tonic attentional control will be exerted, leading to a relatively low level of conflict. Consistently, smaller Stroop interference effects have been reported in task versions with a high probability of incongruent color-words (Carter et al., 1995; Carter et al., 2000; Lansbergen et al., 2007b; Swick and Jovanovic, 2002; Tzelgov et al., 1992; West and Alain, 2000). Electrophysiological chronometric measures may elucidate at which processing stage(s) tonic attentional control occurs. Gratton et al. (1992) incorporated similar probability manipulations in the flanker task, revealing a tendency for a larger incompatibility effect on mean LRP amplitude with decreasing probability of incongruent trials (Gratton et al., 1992). Together, these findings lead to the prediction that a low probability of incongruent trials will increase Stroop interference, and at least enhance competition between responses (word reading and color naming) that affect the build-up of correct or even incorrect selective response activation.

2. Methods

2.1. Participants

Sixteen students that scored extremely low and 16 who scored extremely high on the impulsivity subscale of the I_7 questionnaire were selected from a group of 435 psychology students that filled out the Dutch version of the I_7 questionnaire[1] (Eysenck and Eysenck, 1978; Lijffijt et al., 2005). Three of the participants were

[1] The selection of extreme high and low impulsive students was performed for purposes unrelated to the present report. In an earlier published paper, extreme high and low impulsive students were compared to examine the association between trait impulsivity within the normal population and abnormal Stroop interference (Lansbergen et al., 2007b). Since high and low impulsives did not differ with respect to Stroop interference in terms of reaction time, analyses in this study were conducted across all participants. Additional statistical analyses regarding the ERP data were also performed including impulsivity (high vs. low impulsivity scores) as between-subjects factor to exclude the possible influence of the variable impulsivity on the effects of task version or stimulus type. No group or interaction with group effects were found for P3, s-LRP, nor for r-LRP data.