# Neural correlates of attentional control of conflict processing: fMRI evidence from a Stroop Match-to-Sample Task

**T. Schulte[1], E. M. Muller-Oehring[2], D. Mayer[3], S. Vinco[1], A. Pfefferbaum[1,4], and E. V. Sullivan[2]**

[1]Neuroscience Program, SRI International, Menlo Park, CA, United States, [2]Psychiatry and Beh. Sciences, Stanford University, Stanford, CA, United States, [3]Radiology, Stanford University, Stanford, United States, [4]Psychiatry and Beh. Sciences, Stanford University

## INTRODUCTION

Resolution of conflict between competing stimulus attributes requires inhibition of irrelevant information while attending to the intended attribute. Execution of conflict resolution entails activation of the anterior attention system, involving anterior cingulate and prefrontal cortical circuitry. The posterior attention system, involving the right parietal cortex, is activated in attentional top-down control on processes of perceptual selection and stimulus attribute identification. Whether anterior circuitry invoked by conflict processing is modulated by attentional allocation to one of multiple competing processes (e.g., to color in the color-word Stroop conflict) is unknown. To identify the neural circuits of conflict processing and attentional allocation with functional magnetic resonance imaging (fMRI), we devised a Stroop Match-to-Sample task requiring a decision based on a color cue that directs attention to a specific color and primes the color processing of the Stroop stimulus. Two response-related processes are engaged in the Stroop Match-to-Sample task: a verbal one silently naming the color of incongruent and congruent word-color stimuli, and a manual one for indicating match and non-match decisions. Our paradigm also examined the contribution of motor systems to cognitive conflict processing by presenting blocks of trials that required the same response (motor response repetition) in contrast to blocks of trials that required the different responses (motor response switch). In addition to the influence of parietal attention function on frontal conflict processing, conflict processing may be mediated by motor response repetition vs. switching.

## METHOD

Healthy right-handed adult volunteers (7 women, 7 men; mean age = 23.7 ± 2.7 years) underwent fMRI while performing the Stroop Match-to-Sample task[1,2]. Stimuli were created and presented with PsyScope software. Subjects matched the color of a cue stimulus displayed for 450 ms in the center of the screen to the color of a Stroop target stimulus that appeared for 1100 ms after an interstimulus interval of 300 ms. Total trial duration was 3.3 sec. The color cue either matched or did not match the color of the Stroop target, which was either congruent (word blue written in blue ink) or incongruent (word blue written in red ink). Subjects pressed a YES-key for cue-target color matches and a NO-key for nonmatches, yielding accuracy and reaction time measures. To mix YES- and NO responses two blocks were presented, one containing *incongruent* match and non-match trials (incongruent) and the other containing *congruent* match and nonmatch trials (congruent) in addition to four same-response blocks (congruent-match, congruent-nonmatch, incongruent-match, incongruent-nonmatch). Two runs were presented with 18 blocks per run (1 block = 9 TRs or 6 trials; TR = 2.2 sec). Imaging was performed with a 3.0-T whole body MRI scanner (General Electric Medical Systems, Signa, Waukesha, WI, USA) using an asset GE 3T head coil. Whole-brain fMRI data were acquired with a T2*-weighted gradient echo planar pulse sequence (axial, mode = 2D, Scan timing: TE=30 ms, TR=2200 ms, flip angle=90°, matrix = 64 x 64, slice thickness = 5 mm, 36 slices). Image preprocessing and statistical analyses were performed using the SPM2 software package (Wellcome Department of Cognitive Neurology). A random effect analysis was conducted for group averaging and population interference, where one image per contrast was computed for each subject, and these images were subjected to *t* tests. The contrast of interest were 'incongruent vs. congruent' (Stroop), 'nonmatch vs. match' (Match), and 'mixed vs. same responses' (Response switching). Analyses were carried out with an uncorrected *P* value threshold of 0.001.

## RESULTS

All subjects showed Stroop effects with RTs to incongruent trials longer than to congruent trials ($F(1,12) = 32.1$, $p < .0001$), and cue-target match effects with RTs faster to match trials than to nonmatch trials ($F(1,12) = 9.62$, $p = .009$). RTs and Stroop effects did not significantly differ between mixed- and same-response blocks (overall RT: $F(1,12) = 2.29$, *ns*; Stroop: $F(1,12) = 0.8$, *ns*) nor between women and men (overall RT: $F(1,12) = 0.21$, *ns*; Stroop: $F(1,12) = 0.48$, *ns*). The Stroop contrast (incongruent vs. congruent) was associated with an increased BOLD response in the right inferior parietal cortex (supramarginal gyrus, BA 40), left anterior cingulate cortex (ACC, BA 10), dorsal posterior cingulate cortex (d-PCC, BA 31) and left superior temporal gyrus (Figure left). The Match contrast (nonmatch vs. match cue-target color) was mainly associated with d-PCC (BA 31) activation. The response switching contrast (mixed vs. same response blocks) was associated with an increased BOLD response in left precentral (BA 4) and postcentral (BA 43) gyri and in the culmen of the cerebellum bilaterally (Figure right).

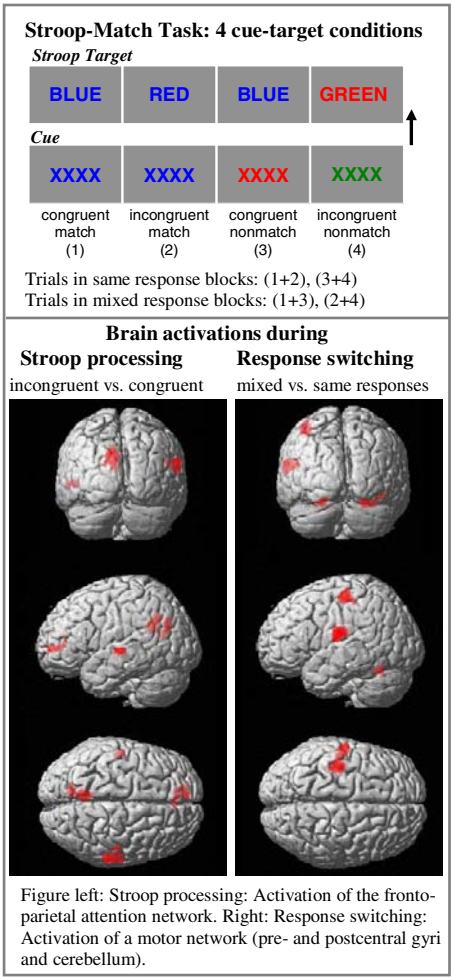


Figure left: Stroop processing: Activation of the fronto-parietal attention network. Right: Response switching: Activation of a motor network (pre- and postcentral gyri and cerebellum).

## DISCUSSION

This fMRI study provides evidence that Stroop conflict processing with pretrial color cueing (Match) is associated with BOLD signal increases in a fronto-parietal attention network involving the left ACC, STG, d-PCC and the right parietal cortex. The ACC is involved in cognitive control processes, such as monitoring response conflict, and the left STG processes language, here, likely reflecting processing the content of the Stroop word. The right parietal cortex is associated with selective attention (e.g., cueing paradigms) and its activation may reflect processes of directing attention to the color in the presence of distracting or incongruent information. PCC activation has been associated with evaluative functions for orienting attention and for memory. Thus, the observed PCC activation may indicate evaluative functions for processes involved in the nonmatch vs. match cue-target color comparison. Despite lack of difference between comparisons in RT, response switching activated a motor network involving the left precentral and postcentral cortices and the cerebellum bilaterally that was not activated in response repetition.

## CONCLUSION

Taken together, these findings show involvement of a fronto-temporo-parietal attention network in cued-Stroop processing, i.e., resolving conflict posed by competing stimulus attributes. These data complement clinical studies that have shown impairment in conflict processing and selective attention in neuropsychiatric conditions that can disrupt this circuitry, including alcoholism[1,2,3,4]. This paradigm provides a novel differentiation of frontal-parietal attention systems and motor systems and lays a foundation for clinical research on identifying sources of disruption of neural systems of attention, conflict processing and motor control.

**References**

[1]Pfefferbaum A, Adalsteinsson E, Sullivan EV (2006). *Biol Psychiatry*, 59:364-372.
[2]Schulte T, Müller-Oehring EM, Rosenbloom MJ, Pfefferbaum A, Sullivan EV (2005). *Biol Psychiatry*, 57:67-75.
[3]Schulte, T, Müller-Oehring, EM, Salo, R, Pfefferbaum, A, Sullivan, EV (2006). *Neuropsychology*, 20:727-736.
[4]Sullivan EV, Pfefferbaum (2005). *Psychopharmacology*, 180:583-94.

**Acknowledgement:** This work was supported by NIAAA grants: AA10723, AA05965