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Intra- and Inter-Hemispheric Stroop Effects

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The classic Stroop interference effect shows slower processing of words when the meaning of a color name (the color word) and the ink color in which it is printed are discrepant. The current study examined the effects of hemispheric lateralization and the spatial separation of a color word and ink color. Stimuli are presented either to the same hemisphere of the brain or opposite hemispheres using tachistascopic presentation of the stimuli while subjects fixate centrally. Reaction times were found to be significantly longer in cases where the color word and ink color were not matched. When the stimuli were matched, RTs were equal regardless of whether they were presented to the same or different hemispheres. However, when there was a mismatch between color word and ink color RTs were slower when the word was presented in the left visual field.

INTRODUCTION

In a classic paper on interference in a reaction time task, Stroop (1935) found that it took longer for subjects to read a list of color names when they were printed in an ink color different from the color named and also that it took longer to correctly identify a list of ink colors when the printed words named colors other than the ink colors in which they were printed. These interference effects are generally attributed to the automatic aspects of the reading process, i.e., the reader's mind automatically determines the semantic meaning of the word and this must be overridden if the subject is to attend to the ink color in which the word is printed. Such an interpretation is supported by the absence of the classic Stroop effect in subjects not familiar with the semantic terms or children who are not yet reading. The basic Stroop paradigm has been widely used to study behavioral inhibition and frontal lobe function (Belanger and Cimino, 2002).

It is generally agreed that the left hemisphere of the human brain is usually more efficient at processing verbal tasks and that the right hemisphere is more efficient at nonverbal, spatial tasks (Gazzaniga, 2000). While the extent of hemispheric specialization is typically overblown in the popular press there is consistent data indicating a general left-hemisphere superiority for language processing and a right-hemisphere superiority for spatial tasks. In this experiment we wanted to examine whether the magnitude of Stroop-like interference would be affected by which hemisphere processed the Stroop stimuli. Given the literature on functional specialization of the cerebral hemispheres one might expect different levels of interference between the semantics of color words and their ink color when these were presented to the left or right hemisphere. We also wanted to examine whether a Stroop-like interference operated between the hemispheres in conditions where the color word and the ink color were processed by different hemispheres as examined by Dyer (1973). To allow an examination of within- and between-hemisphere conditions we used a non-traditional version of the Stroop task where the color word and ink color were spatially separated.

METHODS

Apparatus and stimuli: Stimuli consisted of a color word (blue, green, pink, or red) and a rectangular block of color (blue, green, pink, or red). The words were written in black, Times New Roman font with a font size of eighteen. The rectangular block of color was the same size as the longest word,

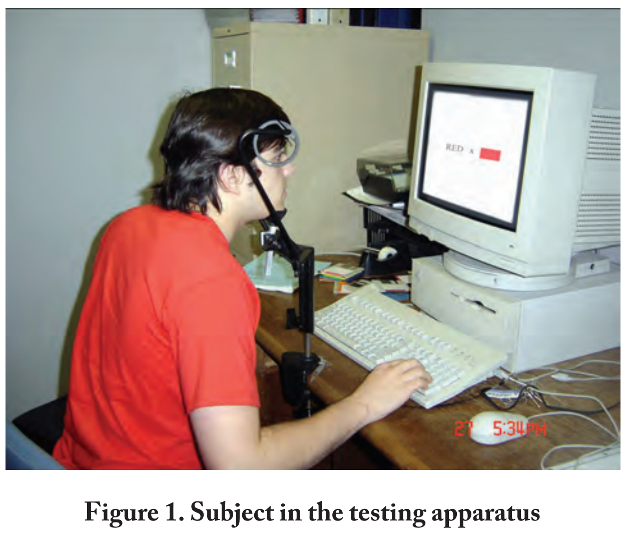
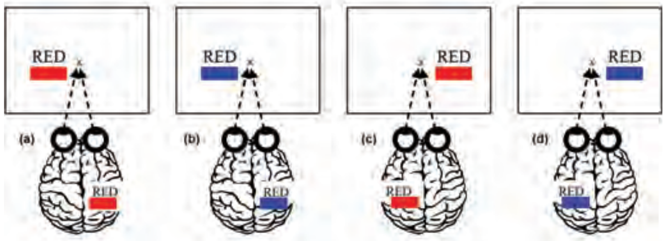


Figure 1. Subject in the testing apparatus

Figure 2: Control stimuli: (a) matching LVF RH, (b) mismatching LVF RH, (c) matching RVF LH, (d) mismatching RVF LH



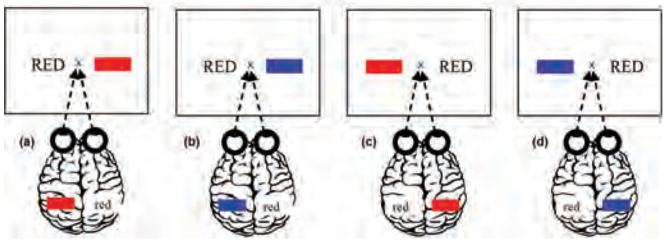


Figure 3: Experimental stimuli: word on (a) matching LVF RH, (b) mismatching LVF RH, (c) matching RVF LH, (d) mismatching RVF LH

"green." The color word and colored block were spatially separated and presented to either the left hemisphere or the right hemisphere or presented to different hemispheres. In all cases the color word was presented above the colored rectangle. The words and colored rectangles were aligned such that the edge nearest the center was 1° away from central fixation. The visual stimuli were presented using a PowerMac computer. Subjects used a chin rest to maintain a viewing distance of 57 cm from the center of the screen (Figure 1).

There were two categories of stimuli: intra-hemishperic (Figure 2) and inter-hemispheric (Figure 3). The intra-hemisphere stimuli consisted of stimuli in which the word and colored rectangle were both presented equally often to either the left or right visual field. There were equal numbers of pairs where the color word matched or failed to match the ink color of the rectangle. The inter-hemisphere stimuli consisted of stimuli where the color word and colored rectangle were presented in opposite visual fields. Again there were equal number of pairs where there was a match or mismatch between the color word and the ink color of the rectangle.

A given trial consisted of a central fixation X appearing for 1,000 ms, followed by a very brief blank interval, followed in turn by the experimental stimuli for 100 ms. Subjects were to indicate as quickly as possible whether the color word matched the ink color of the rectangle or not. Subjects indicated a Match by pressing a pre-selected key on the computer keyboard with their index finger of their right hand and a Mismatch by pressing the adjacent key using their adjacent finger of their right hand. A visual feedback signal (+/1) was given immediately after the subject's response. If the subject failed to respond within 1,500 ms the trial timed out and the next trial was automatically initiated.

Procedure: Four female and ten male undergraduate participants were given a detailed set of instructions about the experiment. The importance of maintaining central fixation

Key
C=Control
E=Experimental
M=Matching
NM=Non-matching
RVF=Right Visual Field
LVF-Left Visual Field
RH=Right Hemisphere
LH-Left Hemisphere
*=Location of "word"

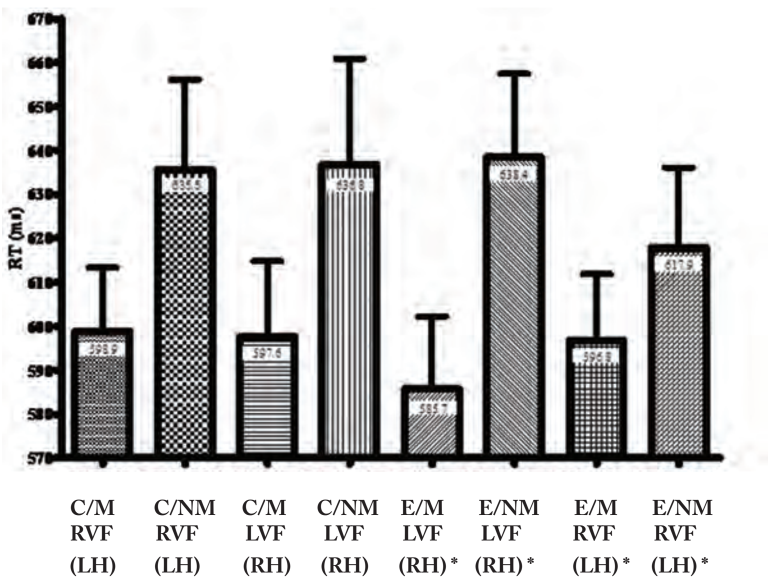


Figure 4. Average RT and SEM for 14 subjects in all eight conditions

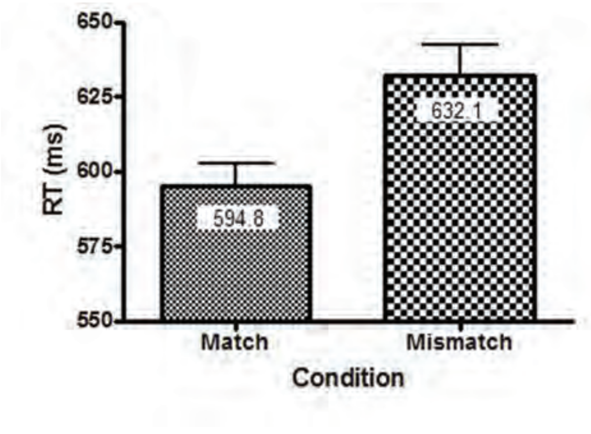


Figure 5. Overall effect of matching and mismatching stimuli

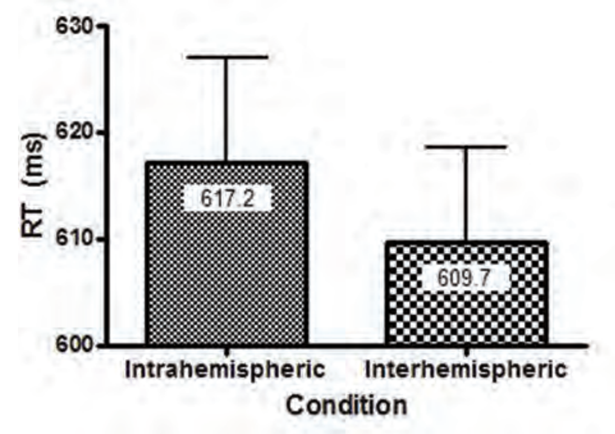


Figure 6. Overall effect of presentation conditions

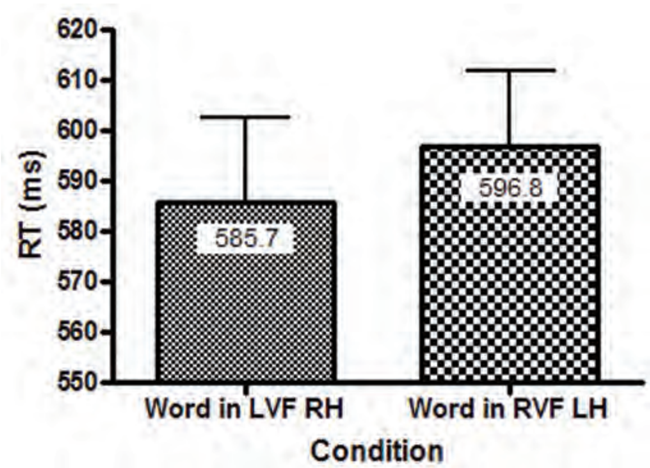


Figure 7. Matched Stimuli (Inter-hemispheric)

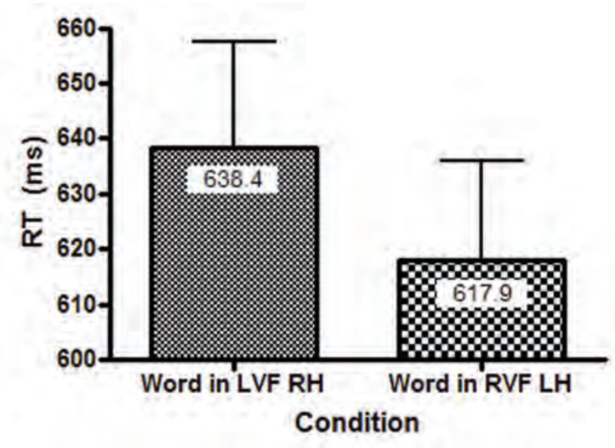


Figure 8. Mismatched stimuli (Inter-hemispheric)

throughout the sequence of trials was stressed. Subjects were instructed to respond as quickly as possible without guessing. They were instructed to minimize their errors and not to sacrifice accuracy for speed. Any questions were clarified before proceeding. Subjects were then asked to complete the Edinburgh Handedness Inventory adapted from Oldfield (1971) to determine which hand was dominant. The subjects were also administered the Neitz Test of Color Vision for color blindness and a standard visual acuity test for near vision. All participants had excellent near visual acuity and were devoid of any color vision deficiency. Subjects were seated in an adjustable chair so that their eyes were level with the central fixation marker on the computer screen. The height of the chin rest was adjusted as necessary. Subjects were given a practice sequence of 48 trials for the intra- and inter-hemisphere type of condition. A sequence lasted about 3 minutes. Additional practice trials were administered if the subject's error rate exceeded 10%. Each subject completed two sequences of intra- and inter-hemisphere conditions alternating between the two with all subjects starting with the inter-hemisphere condition. Subjects were allowed to take breaks as needed between the three-minute test sequences.

The experimenter sat at the back of the room out of the subject's view during all phases of testing.

RESULTS

Only RTs for correct responses were included in the analysis of the data. The error rate was less than 10%.

Figure 4 shows the mean and standard error of the mean for the RTs of the 14 subjects for each of the eight experimental conditions.

In conditions where the color word and color patch were presented to the same hemisphere (the Intra-hemisphere condition) there was no significant difference in RT between stimuli presented to the left and right hemispheres. As expected, RTs were faster for matching stimuli than for mismatching stimuli when data were collapsed across hemisphere and presentation condition ($p<.0001$). Results are shown in Figure 5. A comparison of the intra- and inter-hemispheric presentation conditions failed to reveal a statistically significant difference ($p<.09$). The data presented in Figure 6 suggest however that RTs tend to be faster when the color word and color patch are presented separately to the two hemispheres than when they are both presented to the same hemisphere.

A closer analysis of the inter-hemisphere conditions reveal some interesting trends. There is no significant difference in RT between conditions where the color word is presented to the left or right hemisphere when collapsing across matched and unmatched stimuli ($p<.15$). However, when one examines the inter-hemispheric data separately for matched and mismatched stimuli one finds that when the color word matches the ink color RTs are significantly faster ($p<.05$) when the word is presented to the right hemisphere. When the color word and ink color are not matched RTs are faster ($p<05$) when the word is presented to the left hemisphere. These data are presented in Figures 7 and 8.

RESULTS AND CONCLUSIONS

The present study replicates the classic match/mismatch effect showing faster RT for matched stimuli in comparison to mismatched stimuli. When both the color word and ink color patch were presented to only one hemisphere there were no significant differences in processing time between stimuli presented to the left and right hemispheres. This pattern of results would be expected even in the presence of hemispheric specialization since each hemisphere would have to process both a 'preferred' and 'non-preferred' type of stimulus. A comparison of the intra- and inter-hemispheric presentation conditions indicated a tendency for RTs in the inter-hemispheric conditions to be faster than those in the intra-hemispheric conditions. In the former condition the hemispheres would have received their respective 'preferred' type of stimulus on 50% of the trials without the need for additional callosal transfers. The most interesting data in the current study came from an examination of the inter-hemispheric stimulus conditions. As in Dyer (1973) there appears not to be a significant difference in processing time between the left and right hemispheres when the word is presented in one hemisphere and the ink color in the opposite hemisphere. Based on hemispheric specialization one might predict that RT would be faster when the left hemisphere received the color word and the right hemisphere received the ink color patch compared to the opposite situation. Unlike previous investigators the current study allowed for a more fine-grained analysis of trials that were matches and mismatches. This revealed an interesting pattern of results. In the match trials, RT was significantly faster when the color word was presented to the right hemisphere and the ink color to the left hemisphere. On the surface this seems to contradict what we know about left hemisphere specialization for verbal material. However if one assumes that the presentation of the ink color patch to the left hemisphere initiates a process to generate a color-word label then by the time the color word is transferred from the right hemisphere the two color labels can be matched and no further processing is needed to generate the right-handed response. In match trials where the color word is presented to the left hemisphere and the ink color patch is presented to the right hemisphere, processing is slower relative to the above condition. It is hypothesized that while the initial processing of the color word in the left hemisphere and the initial processing of the ink color patch in the right hemisphere is relatively fast, additional time is needed to transfer the color stimulus to the left hemisphere and generate a verbal label which can then be matched with the already processed color word. One can adopt a similar explanatory framework for an opposite pattern of results for mismatch trials. In mismatch trials RT was faster when the color word was presented to the left hemisphere and the ink color patch was presented to the right hemisphere. In these conditions the left hemisphere presumably processed the color word quickly and the right hemisphere processed the ink color patch quickly. For the decision to be made and a right-handed response to be generated, the ink color stimulus would have to be transferred to the left hemisphere, a verbal label generated for the ink color, and additional time taken for the mismatch in verbal labels to be resolved. Mismatch trials in which the color word was presented to the right hemisphere and the ink color patch was presented to the left hemisphere were much slower. As in the match conditions described above, the presentation of the ink color patch to the left hemisphere initiates a process to generate a color-word label while the color word is transferred from the right hemisphere. However because of the mismatch it is hypothesized that the ink color stimulus must be sent to the right hemisphere for more in-depth processing before a correct response can be made. This additional processing step serves to lengthen the RT. These hypotheses regarding the opposing biases in hemispheric advantages revealed by the separate analyses of matched and mismatched trials will be examined in future studies.

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