RELATING SEARCH AND STROOP PHENOMENA

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Abstract

Presented with Stroop color-word stimuli, participants were asked to make one response ("Yes") to the appearance of the word RED, the color red, or both and another response ("No") when none of these targets (defined by redness) appeared. The same participants also performed in the standard Stroop task, naming the print color of the same set of color words. Because we were careful to (1) construct stimuli equally discriminable on color and word, and (2) combine color and word such that there was zero correlation over the experimental trials between the two components, no Stroop effect was found. The results of the search task, augmented by Townsend's double factorial paradigm, showed the underlying system to be minimum time parallel, independent, and unlimited capacity. Collectively, the results support the contextual approach to the Stroop phenomenon by which it is neither robust nor inevitable.

A taxonomy for elementary cognitive processes developed by Townsend (1974, 1990; Townsend & Ashby, 1983) has been augmented by a mathematical theory and related experimental methodology (Townsend & Nozawa, 1995; Wenger & Townsend, 2000) to permit strong tests and conclusions regarding the properties of the cognitive system under investigation. Four logically distinct but often interrelated characteristics of information processing are *architecture* (serial vs parallel, and, within the latter, separate vs coactive), *capacity* (limited vs unlimited vs supercapacity), *stopping rule* (self-terminating vs exhaustive), and *stochastic dependence* (dependence vs independence). The prototypical experimental setup to uncover these properties comprises visual search within the "redundant target design." Of the set of possible stimuli, some are defined as targets. The observer is to make a certain response if one or more targets appear in a display and a different response if no target is presented. Speeding up on trials with multiple (i.e., redundant) targets typically occurs relative to trials with fewer targets – the redundant target effect. The magnitude and distribution features of the redundancy effect then serve to uncover the noted characteristics of the particular cognitive system.

Recently, Townsend and Nozawa (1995) have developed a novel paradigm, the double factorial design, which further aids in model diagnosis. In that design, a second variable such as saliency or intensity is manipulated apart from that of the presence of the target. The two factors are crossed with each other; hence the double factorial design. Given the added factor, strong factorial test of architecture and (in)dependence are possible with the subset of data in which all the targets are present. These tests are independent of the capacity analyses routinely performed on the single vs multiple target trials. The bifurcated analysis permits stronger evidence on the underlying properties of the cognitive system under investigation.

In the current study, we applied the double factorial design for an examination of the Stroop phenomenon (Stroop, 1935). The single most popular phenomenon within cognitive psychology, the Stroop effect is the classic example of the human failure to attend selectively:

Naming the print color of color words is impaired by the meaning of the words, although reading the words is not similarly hindered by irrelevant print color. Selective attention fails for color, but it is perfect for word. The Stroop effect has accrued theoretical interest because, presumably, the effect is the inescapable outcome of pitting the automatic process of word reading against the less automatic or controlled process of color naming. Because reading is more automatic and speedy than naming, the latter suffers intrusions from involuntary word reading, but reading is not similarly hampered by conflicting print color. Recently, we (Algom, Dekel, & Pansky, 1996; Dishon-Berkovits & Algom, 2000; Melara & Mounts, 1993; Pansky & Algom, 1999 ; Sabri, Melara & Algom, 2001; Shalev & Algom, 2000) have challenged both the alleged robustness of the Stroop phenomenon and its traditional explanations. We demonstrated that the effect is malleable experimentally by several factors of context. By judiciously manipulating these factors, one is able to determine the direction, the magnitude, and, in fact, the very presence of the Stroop effect. Hence, the effect is neither robust nor, indeed, inevitable. These results, in turn, cast doubt on theories positing the automatic activation of the meaning of words.

To distinguish between the disparate approaches to the Stroop phenomenon and, hopefully, to aid in theoretical resolution, we decided to apply the double factorial design of visual search to the original Stroop stimuli. The stimulus set comprised the factorial combination of the color words, RED, and GREEN, and the print colors, *red,* and *green*. As in the classic Stroop task, a single color word printed in color appeared on a trial. Redness was defined as the target: The participant was to press one key ("Yes") if either the word RED, the print color *red* or both were presented; otherwise she or he was to press another key ("No"). The added factor was saliency: We degraded the quality of the font, the quality of the color, or both on some of the trials. In a separate session, the participants also performed in the classic Stroop task with the same stimuli. They named, while timed, the print colors of color words. The Stroop effect was calculated as the difference in performance between congruent (the word naming its print color) and incongruent (conflicting word and color) stimuli.

Method

There were a total of 19 sessions: 1 practice for visual search, 16 data collecting on visual search, 1 practice for color naming in a Stroop task, and 1 data collecting for the Stroop task. The practice session for visual search comprised 256 trials as did each of the data collecting sessions. The Stroop practice session comprised 64 trials, and the Stroop data collecting session comprised 256 trials. There was trial-to-trial spatial uncertainty of 20 pixels around the central location of the color word. Responses in both tasks were made manually, by pressing one or the other of two preset keys. In both tasks, the four possible stimuli were equally probable. Given the confines of the present report, we present the detailed results of one participant (AA), typical of the data of all the other participants.

Results

The results with respect to the Stroop task are easily summarized: There was no significant effect of Stroop in the data. Incongruent stimuli were named 343 ms on average, and congruent stimuli were named 337 ms on average. The difference, 6 ms, amounted to a minuscule effect of Stroop that was negligible. The absence of a Stroop effect is notable: When naming the colors, the participant suffered no interference from the conflicting words. We implicate the following two factors of context for the null result: approximately matched *discriminability* of the colors and words used, and zero *correlation* over the experimental trials between word and color. We used words that were as easy (or difficult) to read as were the print colors to name. Then, the colors and words were combined in a strictly random fashion such that neither was predictive of the other. The absence of a Stroop effect supports our contention that the Stroop effect is not inevitable, but rather is the contingent result of biased experimental designs.

In the remainder of this report we summarize the results of the visual search task. The mean RTs in the redundant target condition are shown in Figure 1. The form of the interaction is clearly overadditive, supporting self-terminating (minimum processing time) parallelity. The positive interaction argues against seriality and exhaustive processing. The same conclusions are even more compelling in Figure 2 which shows the respective survivor functions (one minus the cumulative distribution functions). The ordering of the survivor functions comprises stronger evidence for parallel processing than the mean RTs. A factorial plot of the type presented in Figure 1, summarized by the difference of the differences in each function between its two extremes, can be applied to the survivor functions of Figure 2 at each of point (bin) of time. In Figure 3 we present these mean survivor contrasts as a function of time. The interaction contrast function is overwhelmingly positive, arguing again against serial processing (whether self-terminating or exhaustive) and parallel exhaustive processing. By the same token, the evidence is impressive for parallel minimum time processing. The small negative blip at short RTs may signal the operation of parallel channels with a summation of channel information (coactivation).

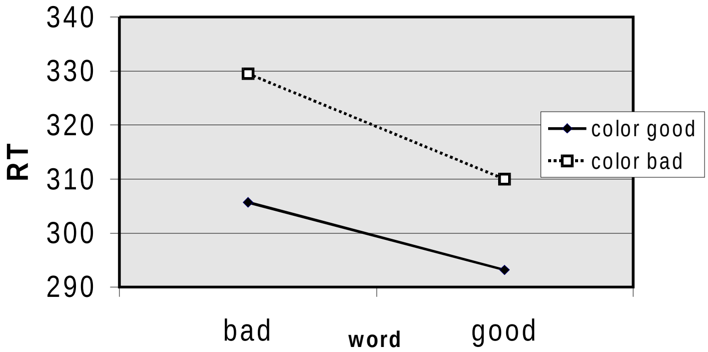

Figure 1: Mean interaction contrast

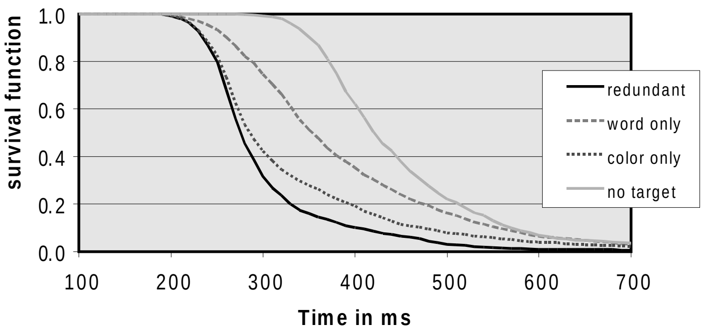

Figure 2: Estimated survivor functions

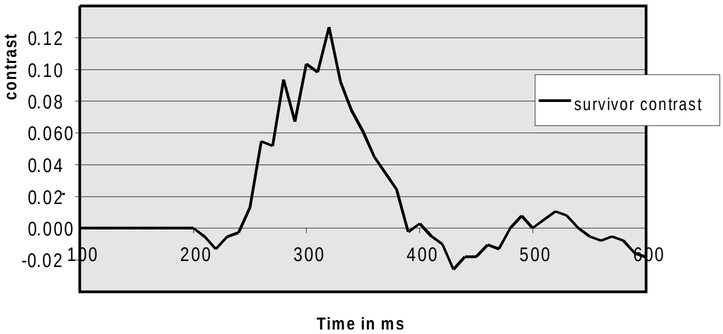

Figure 3: Survivor interaction contrasts

We next assess redundant target and capacity effects based on the entire factorial design (i.e., not on the subset of redundant targets that formed the platform for the previous analyses). In Figure 4, we compare performance in the two-target condition (i.e., RED in *red*) with that expected on the basis of independent unlimited capacity (parallel) processing. The C(t) coefficients, ratios of integrated hazard functions, were between 0.7 and 1.0, supporting unlimited capacity [C(t) = 1.0] to very slightly limited capacity. Conspicuously missing from the data is supercapacity. Miller's (1982) famous inequality is not violated (Figures 5 and 6), an outcome reinforcing the absence of supercapacity. On the other hand, AA's data did not violate Grice's inequality, showing that processing was not severely limited capacity.

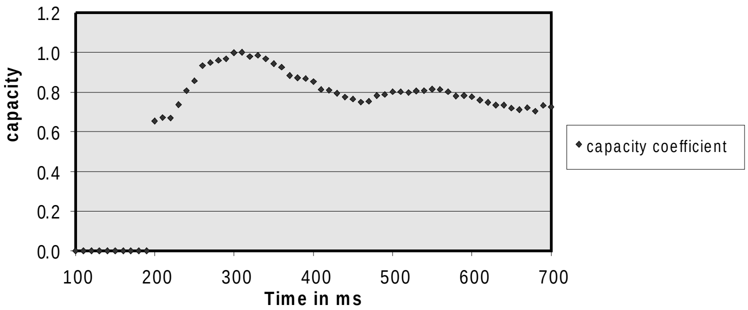

Figure 4: Capacity coefficient plot

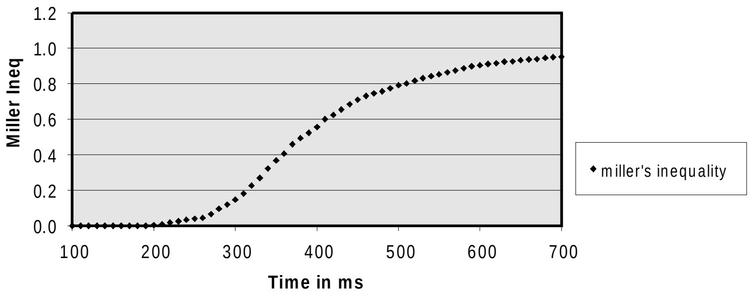

Figure 5: Potential violation of the Miller inequality

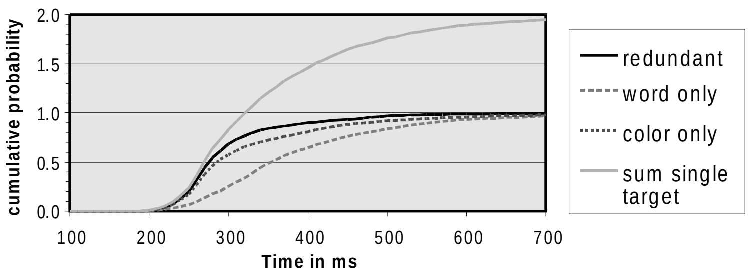

Figure 6: Cumulative pdf vs summed single pdf

Conclusions

Let us take stock. The system underlying classification with color-word Stroop stimuli is (1) minimum time, (2) strictly independent, (3) parallel (possibly coactive), and (4) approximately unlimited capacity. What are the implications of these properties for theories of the Stroop effect? First, the lack of supercapacity implies that color and word do *not* coalesce into a unified stimulus forming a gestalt. They are *not* processed together as a unified whole. As a result, slower color naming for incongruent stimuli (RED in *green*, GREEN in *red*), if present, can *not* be attributed to redundancy engendered by semantic conflict inhering in the color-word stimulus. Second, stochastic independence implies the lack of a cross talk between the word and color channel. Third, minimum time parallel processing implies that information from the color and information from the word are processed in separate channels, and a response is made once a preset criterion is reached in either channel. Finally, even if evidence from the word and the color channels is summed before a detection response is made (i.e., there is coactive summation), the summation does not amount to authentic integration of information.

Given these conclusions, whence the Stroop effect? The real answer to this question is that indeed there is no Stroop effect present when care is taken to remove various biases from the experiment. In virtually all of the experiments in the vast Stroop literature, the words were more discriminable than the colors. Similarly, an insidious creeping into the experimental design of a hidden correlation between color and word characterizes the vast majority of the Stroop studies in the literature. Other biases abound. Their net effect is speeding up the word channel relative to the color channel, with the word response preempting a possible response from the color channel. Stroop effects ensue. However, they do not derive from any integration of the color and the word, nor from privileged semantic processing. Indeed, an impressive feature of the present results is the complete symmetry of the two channels. Word processing does not differ qualitatively from color processing, challenging accounts of automaticity. In summary, the collective results of this study bear out the main tenets of the contextual approach to the Stroop phenomenon advocated by Melara and Algom.

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