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# Further investigation of distinct components of Stroop interference and of their reduction by short response-stimulus intervals

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ABSTRACT

The aim of this paper is to extend the so-called semantic Stroop paradigm (Neely & Kahan, 2001) – which already successfully distinguishes between the contribution of the semantic vs. response conflict to Stroop interference – so that it can take account of and capture the separate contribution of task conflict. In line with this idea, the Stroop interference observed using the aforementioned paradigm with both short and long RSIs (500 vs. 2000 ms) did indeed reflect the specific contribution of the task, semantic and response conflicts. However, the contribution of task conflict (as opposed to the semantic and response conflicts) failed to reach significance when the semantic Stroop paradigm was administered with manual (Experiment 1) as opposed to vocal responses (Experiment 2). These experiments further tested the extent to which the specific contribution of the different conflicts can be influenced by the increased cognitive control induced by a short (vs. long) RSI. The corresponding empirical evidence runs contrary to the assumption that the reduction of overall Stroop interference by a short (vs. long) RSI is due to the reduced contribution of the task (Parris, 2014) and/or semantic (De Jong, Berendsen, & Cools, 1999) conflicts. Indeed, in neither experiment was the contribution of these conflicts reduced by a short RSI. In both experiments, this manipulation only reduced the contribution of the response conflict to the overall Stroop interference (e.g., Augustinova & Ferrand, 2014b). Thus these different results clearly indicate that Stroop interference is a composite phenomenon involving both automatic and controlled processes. The somewhat obvious conclusion of this paper is that these processes are more successfully integrated within multi-stage accounts than within the historically favored single-stage response competition accounts that still dominate current psychological research and practice.

## 1. Introduction

The Stroop task (Stroop, 1935) requires individuals to identify, as quickly and accurately as possible, the font color of written characters without reading them. Despite this requirement, the typical result is that individuals' identification times are longer and more error-prone for *color-incongruent* Stroop words (i.e., words displayed in a color that is different from the one they designate such as “BLUE” displayed in green ink; hereafter $BLUE_{green}$), than for *color-neutral* items (e.g., “DOG”/“XXX” displayed in green ink, $DOG/XXX_{green}$).

This difference – called Stroop interference – is often thought to result from the so-called *response conflict* (e.g., MacLeod, 1991; MacLeod & MacDonald, 2000) present in the aforementioned color-incongruent Stroop words (e.g. $BLUE_{green}$). This conflict is thought to arise because word reading is routinized through practice. Consequently, the irrelevant word dimension of these words (i.e., blue for $BLUE_{green}$) provides evidence towards a response that is thought to interfere with the one cued by the relevant color dimension (i.e., green here).

This latter consideration – which is shared by so-called *single-stage response competition accounts* (see e.g., Risko, Schmidt, & Besner, 2006 for this terminology) – contrasts with the results of several more recent lines of research. These lines of research – that have given rise to what is termed *multi-stage accounts* (Risko et al., 2006) – suggest that Stroop interference is a more complex phenomenon that goes beyond a single (i.e., response) conflict depicted above. Currently however, these accounts diverge with regard to the types of conflicts involved in Stroop interference. Thus the present paper addresses just this issue.

### 1.1. Which types of conflicts does Stroop interference actually involve?

The single-stage response competition accounts (also called *late-*

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*selection accounts*) have historically been favored in the Stroop literature, first over so-called *early-selection accounts* (e.g., Logan & Zbrodoff, 1998; MacLeod, 1991; Risko et al., 2006). These other kinds of single-stage accounts share the idea that Stroop interference results solely from a conflict that occurs much earlier in processing than the aforementioned response conflict.[1]

Seymour (1977) considers for instance that this *semantic conflict* occurs precisely at conceptual encoding of color-incongruent words (e.g. $BLUE_{green}$). In this view, "(…) delays of processing occur whenever distinct semantic codes are simultaneously activated, and that these delays become acute when the conflicting codes are values on a single dimension or a closely related dimensions." (Seymour, 1977, p. 263; see also e.g. Luo, 1999; Scheibe, Shaver, & Carrier, 1967; Seymour, 1974, 1977; Stirling, 1979). In sum, this conflict occurs in the amodal semantic network because the meaning of the word dimension and that of the color dimension both correspond to colors.

The first systematic conceptualization of multi-stage processing in the Stroop task arose specifically from a critique of the opposition between early and late-selection accounts. Specifically, Zhang and Kornblum (1998) point to the fact that "These two proposals (…) focus on one particular aspect of the Stroop task to the exclusion of the other. The early-selection account focuses on the similarity between the relevant stimulus and the irrelevant stimulus, whereas the late-selection account focuses on the similarity between the irrelevant stimulus and the response. Both similarity relationships are, of course, present in the Stroop task – in fact, they constitute a confounding that makes distinguishing empirically between the two accounts difficult." (p. 4).

It is thus not surprising that later multi-stage accounts assumed the existence of both *stimulus* and *response* conflicts (e.g., Augustinova & Ferrand, 2014b; De Houwer, 2003; Manwell, Roberts, & Besner, 2004; Neely & Kahan, 2001; Schmidt & Cheesman, 2005; Zhang & Kornblum, 1998; see also e.g., Augustinova, Silvert, Ferrand, Llorca, & Flaudias, 2015; Chen, Lei, Ding, Li, & Chen, 2013; Killikelly & Szűcs, 2013; Szűcs & Soltész, 2010; Van Veen & Carter, 2005 for electrophysiological and fMRI evidence).

Several other multi-stage accounts also assume that Stroop interference results from the simultaneous contribution of two distinct conflicts. However, in addition to the response conflict, they assume the existence of so-called *task conflict* instead of the semantic conflict assumed by earlier accounts.

Task conflict is thought to arise because the individual's attention is drawn to the irrelevant (i.e., word reading) task instead of being fully focused on the relevant (i.e., color naming) task (e.g., Goldfarb & Henik, 2006, 2007; Kalanthroff, Goldfarb, & Henik, 2013; Kalanthroff, Goldfarb, Usher, & Henik, 2013; MacLeod & MacDonald, 2000; Monsell, Taylor, & Murphy, 2001; Parris, 2014; see also e.g., e.g., Bench et al., 1993 for fMRI evidence).

For instance, Monsell et al. (2001) incorporated task and response conflicts in what they termed a *two-factor account* of Stroop interference. More specifically, they argued that "(…) when a stimulus affords multiple responses, as with a colored word, there may be two sources of interference with the performance of the weaker task, color naming. The first is competition at the level of whole task sets. (…) The second is competition from a specific response tendency, the word's name, activated in spite of the intended suppression of the reading task set." (p. 149).

To sum up, both types of multi-stage accounts depicted above emphasize the contribution of two distinct conflicts to overall Stroop interference. The first type suggests that it results from *semantic* and *response* conflicts (hereafter SC-RC accounts) whereas the second type suggests that the overall Stroop interference results from *task* and *response* conflicts (hereafter TC-RC accounts). Given that the considerable empirical evidence points to the viability of each of them, the empirical work presented in this paper adopts the integrative assumption that all three conflicts – task, semantic and response conflicts – expected by these accounts are specific in their nature and that they thus all contribute to standard (i.e., overall) Stroop interference. In line with this idea, the first empirical objective of this work is to examine the extent to which their distinct contribution can be reliably captured in the so-called *semantic Stroop paradigm* (see Neely & Kahan, 2001 for the initial theoretical impetus, and e.g., Augustinova & Ferrand, 2014ab for the review of later empirical implementations).

### *1.2. How to (potentially) capture task conflict in the semantic Stroop paradigm?*

In its current form, the semantic Stroop paradigm supplements standard color-incongruent (e.g., $BLUE_{green}$) and color-neutral (e.g., $DOG_{green}$) words that are commonly used in the standard Stroop paradigm with color-associated words (e.g., *SKY* displayed in green, hereafter $SKY_{green}$ first introduced by Klein, 1964). This addition – initially suggested by Neely and Kahan (2001) – follows the aforementioned logic underlying SC-RC accounts. Such that it assumes the presence of *semantic conflict* in both associated and standard color-incongruent words and the presence of *response conflict* only in standard color-incongruent words.

Indeed, because the meaning activated by the irrelevant word dimension of both color-incongruent words (e.g., $BLUE_{green}$ and $SKY_{green}$) corresponds to and/or is closely related to a color (blue here), it subsequently slows processing of the meaning that is activated by the color-dimension (e.g., green) of these words (see Seymour's reasoning about semantic conflict above). Inversely, because the meaning activated by the irrelevant word dimension of color-neutral words (e.g., dog for $DOG_{green}$) is not related to a color, these items are free of semantic conflict.

Additionally, once the irrelevant word dimension of standard color-incongruent words (e.g., $BLUE_{green}$) has been adequately processed, it primes a specific (pre-)response tendency that shares the same response set (hence interferes with) that the one primed by the meaning of the relevant color dimension (see e.g., Monsell and colleagues' reasoning about response conflict above). Inversely, because the word dimension of associated color-incongruent words (e.g., $SKY_{green}$) does not activate (pre-)motor responses linked to the associated color (e.g., press a blue button on seeing *SKY*; see Schmidt & Cheesman, 2005 for a direct demonstration), their response set does not overlap with that activated by the color-dimension. Consequently, associated color-incongruent words (e.g., $SKY_{green}$) are, exactly like color-neutral ones ($DOG_{green}$), free of response conflict (but see e.g., Hasshim & Parris, 2014, 2015; Klein, 1964 for a different view).

In line with these assumptions, the semantic Stroop paradigm allows observing the delay in processing (i.e., interference) for both types of color-incongruent words compared to color-neutral ones with the magnitude of this interference being greater for standard as compared to associated color-incongruent words (e.g., Augustinova & Ferrand, 2012a, 2012b, 2014a; Augustinova, Flaudias, & Ferrand, 2010; Augustinova et al., 2015; Ferrand & Augustinova, 2014, Manwell et al., 2004; Schmidt & Cheesman, 2005, see also e.g., Risko et al., 2006; White, Risko, & Besner, 2016).

Thus, contrary to TC-RC accounts and in line with SC-RC accounts, this evidence suggests that the contribution of *semantic conflict* (e.g., $SKY_{green} - DOG_{green}$) to overall (i.e., standard) Stroop interference (e.g., $BLUE_{green} - DOG_{green}$) cannot be equated with the one of *response conflict* (e.g., $BLUE_{green} - SKY_{green}$).

Conversely, and in line with TC-RC accounts, the semantic conflict cannot be equated with the task conflict. Indeed, the semantic Stroop

[1] This conflict is usually referred to as *stimulus conflict* – a term that is rather agnostic with respect to its underlying processes. Indeed, some early-selection accounts posit that these processes are perceptual (e.g., Hock & Egeth, 1970), some others that they are conceptual (i.e., semantic, Seymour, 1977) in their nature. Given that this paper subsequently focuses on this latter view, we only introduce the idea of semantic conflict (but see e.g. MacLeod, 1991 for a complete view of this issue).