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Modulation of conflicts in the Stroop effect

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A B S T R A C T

The purpose of the current study was to evaluate the unique contribution of task conflict, semantic conflict and response conflict to the Stroop effect and to test how these conflicts are modulated by manipulating the proportion of neutral trials, known to affect the magnitude of the Stroop effect. In the first experiment, we employed the two-to-one paradigm (De Houwer, 2003) while adding neutral illegible stimuli, and in the second experiment, we employed two colors and four word colors. In both experiments, we created four congruency conditions (neutral, congruent and two kind of incongruent conditions—those that include response conflict and those that do not), which allowed decomposing the Stroop effect into three orthogonal conflicts. In both experiments, we also manipulated the proportion of neutral trials. Task conflict was defined by the contrast between illegible neutrals and color words, semantic conflict by the contrast between congruent and incongruent stimuli, and response conflict by contrasting the two kinds of incongruent stimuli. Our results showed that all conflicts contributed to the Stroop effect. Task conflict and semantic conflict were modulated by the proportion of neutrals but response conflict was not. These findings imply that task conflict and semantic conflict are part of the control loop of the Stroop effect, as conceptualized by Botvinick et al.'s (2001) conflict monitoring model. There is no clear evidence of the response conflict being part of the loop. To complete the picture, we also analyzed the conflicts in the Stroop task using the traditional dependent contrasts approach and found the basic pattern of results was similar. Thus, the main advantage of the orthogonal comparisons approach is the possibility to estimate the unique contribution of the conflicts contributing to the Stroop effect and their modulation of the Stroop phenomenon.

1. Introduction

One of the most frequently used tasks in cognitive psychology is the Stroop task (MacLeod, 1991; MacLeod & MacDonald, 2000). It is widely accepted as the "golden standard" of attentional measures (MacLeod, 1992). In this paradigm, participants are requested to respond as fast and accurately as they can to the ink color of the presented stimuli while ignoring the word content (Klein, 1964; Stroop, 1935; for a review see MacLeod, 1991). Usually the task consists of three types of stimuli—congruent, incongruent and neutral.

In the congruent condition, the meaning of the word and the ink color have the same semantic meaning (e.g., the word BLUE written in blue ink), while in the incongruent condition, the color word and the ink color do not share the same semantic meaning (e.g., the word BLUE written in green ink). In the neutral condition, the presented stimuli are illegible, or at least are not color-related words, and thereby do not activate color representation (e.g., the word "chair" written in blue or the string of letters "XXXX" written in red). Typically, responses to incongruent stimuli are slowest, responses to congruent stimuli are fastest and responses to neutral stimuli are in between (for a review see MacLeod, 1991).

Two dominant interpretations to explain the origins of the Stroop effect have evolved throughout the years. The first is based upon the assumption that reading is more automatic than color naming (MacLeod, 1991) and as such, it runs to completion without conscious monitoring (Bargh, 1989; Tzelgov, 1997). The Stroop phenomenon has been introduced as a prime example of automatic processing (Posner & Snyder, 1975). Automatic processes are autonomous, they may occur without intention, be triggered by the presence of a relevant stimulus, and they run to completion ballistically (Logan, Zbrodoff, & Williamson, 1984). Consequently, skilled readers cannot prevent themselves from reading words, even when doing so hampers their performance in the Stroop task (Augustinova & Ferrand, 2014; Brown, Gore, & Carr, 2002). An alternative view attributes the effect to

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the informational relations among the dimensions involved in the Stroop task. Kornblum and his collaborators (Kornblum, Hasbroucq, & Osman, 1990; Zhang & Kornblum, 1998; Zhang, Zhang, & Kornblum, 1999) see the Stroop phenomenon as resulting from the dimensional overlap between the dimensions defining the stimuli. In particular, in the Stroop task there is an overlap between the members of each pair of the three dimensions involved; between the relevant and the irrelevant stimulus dimension, and between each of the stimulus dimensions and the response dimension. Dimensional overlap is a precondition for the congruency relation that Algom and colleagues (Algom, Chajut, & Lev, 2004; Melara & Algom, 2003) see as the defining feature of the Stroop phenomenon. Dishon-Berkovits and Algom (2000) suggested that words do not activate their meanings automatically, but rather the semantic-level activation is subjected to attentional control caused by the information provided by values of the specific stimuli involved. Therefore, they concluded that the experimenter indirectly governs the attentional processing and influences the outcomes of the participants. Thus, following this view, performance is mainly affected by the contradicting information resulting from color naming and reading, rather than by the automatic tendency of reading per se.

1.1. Disentangling the conflicts of the Stroop task

Following the two interpretations of the Stroop effect mentioned above, MacLeod and MacDonald (2000) framed the Stroop phenomenon as reflecting two conflicts; task conflict (TC) and informational conflict (IC). TC refers to the fact the participants perform two tasks although they are required to perform only one. That is, two competing tasks are activated—one through task demands (color naming) and the other (reading) due to its automaticity (Entel, Tzelgov, Bereby-Meyer, & Shahar, 2015; Kalanthroff, Goldfarb, Usher, & Henik, 2013; Levin & Tzelgov, 2014; MacLeod & MacDonald, 2000; Monsell, Taylor, & Murphy, 2001; Parris, 2014). IC refers to the contrasting information resulting from color naming and reading in the incongruent conditions (Entel et al., 2015; Kalanthroff, Goldfarb, & Henik, 2013; Kalanthroff, Goldfarb, Usher, et al., 2013; Kalanthroff & Henik, 2014; Levin & Tzelgov, 2014; MacLeod, 1991; MacLeod & MacDonald, 2000). A similar two-component framework with focus on goal maintenance, which depends on working memory capacity, and conflict resolution was suggested by Kane and Engle (2003; see also Morey et al., 2012). Note, that following the two-conflict view, neutral illegible stimuli are in fact conflict-free and thus should be responded to faster than congruent stimuli, in particular when the former are unreadable (Entel et al., 2015). Following this logic, neutral stimuli should be processed faster than congruent stimuli, at least in some conditions, due to lack of task conflict, while incongruent stimuli should be responded to slowest due to the involvement of both TC and IC. However, as already mentioned, this is not the typical finding in most of the studies reported. Goldfarb and Henik (2007) were the first to provide a direct indication for task conflict by generating conditions of "negative facilitation" (faster responses to neutral compared to congruent stimuli). Using a similar paradigm, Kalanthroff and his colleagues replicated the existence of negative facilitation (Kalanthroff, Goldfarb, & Henik, 2013; Kalanthroff, Goldfarb, Usher, et al., 2013; Kalanthroff & Henik, 2014), as did others (e.g., Parris, 2014). However, in our view, negative facilitation should not be equated with TC. Instead, negative facilitation is a specific marker of TC. The TC component occurs in the Stroop effect even in the absence of negative facilitation. It arises due to the activation of the two tasks that are at the core of the phenomena - the relevant task—naming the color—and the irrelevant task—reading the word. Therefore, Entel et al. (2015; see also Levin & Tzelgov, 2016) used a different approach. In particular, they adopted the approach of orthogonal contrasts, which allows decomposing the variation via experimental conditions into non-overlapping or uncorrelated components (Rosnow, Rosenthal, & Rubin, 2000; Winer, Brown, & Michels, 1971) of variability. Each contrast is defined by a set of weights given to the means of the various experimental conditions. Entel et al. (2015) presumed that TC exists for all readable stimuli and consequently proposed that in the context of the Stroop task, TC should be measured by the contrast between color words (congruent and incongruent) and illegible neutral stimuli that do not activate lexical processing (Brown, 2011; Levin & Tzelgov, 2016). By this approach, the neutral condition reflects only task conflict and is contrasted to the means of all conditions that reflect both task conflict and semantic conflict. This results in the weights (-1, -1, 2) given respectively to the means of the congruent, incongruent and neutral conditions. If one accepts the assumption that the mean of all conditions reflecting a specific conflict provides the best estimate of this conflict, then by using this approach, it enables estimating the unique contribution of each conflict in terms of its variability between the congruency conditions. Thus, in the specific case of a Stroop experiment that includes neutral, congruent, and incongruent stimuli, using the above-defined weights for defining TC and another contrast between congruent and incongruent stimuli allows estimating the independent contribution of the two conflicts. According to Entel et al. (2015), IC is measured as the contrast between congruent and incongruent stimuli that both cause task conflict by being readable, but only one of them (the incongruent condition) causes informational conflict, due to different information provided by the word and its color. The independence of the two contrasts can be shown by computing the covariance[1] of their weights. Despite the statistical advantages of the orthogonal contrasts approach (i.e., their mathematical independency implies that the result of one contrast cannot influence the results of the remaining contrasts, see Howell, 2012), it is not the prominent approach in examining the conflicts within the Stroop effect. Traditionally, contrasts in the Stroop effect are examined via a set of dependent contrasts—the TC is examined as the comparison between neutral stimuli and color words, which does not contain a semantic conflict (i.e., congruent stimuli), and the IC is measured as the comparison between congruent and incongruent stimuli (MacLeod & MacDonald, 2000).

The present study extends the approach of the Stroop effect phenomenon proposed by Entel et al. (2015) by further decomposing the informational conflict. Note that IC has in fact two components. One is due to the crosstalk between relevant and irrelevant dimensions; for example, the word "RED" appearing in blue leads to automatic activation of the color "red" and thereby interferes with processing of the color "blue" (Hock & Petrasek, 1973). We refer to this component as the semantic conflict (SC). However, in the standard design in Stroop experiments each color requires a different response, which results in response conflict (RC) in the case of incongruent stimuli. This conflict has two aspects—response decision and response generation. The former reflects activation of two color names, each activated via different dimensions (word and color), while the latter reflects the motor differences in the articulation of a specific word or a specific keypress generated by a color word. In any case, in the standard design, SC and RC are confounded and referred to together as IC. Thus, in the present study we wish to disentangle the confound in IC and to demonstrate that the Stroop effect has in fact three distinct conflict components—TC, SC, and RC.

De Houwer's (2003) two-to-one paradigm is one possible way to disentangle informational conflict into its components of SC and RC. In this paradigm, four color words and their names are used, but the four ink colors are mapped into two response keys (e.g., the colors "RED" and "BLUE" are assigned to the "a" button while the colors "YELLOW" and "GREEN" are assigned to the "k" button). Van Veen and Carter (2005) elaborated De Houwer's findings by using neuroimaging (fMRI – functional magnetic resonance imaging) and concluded that not only do

[1] The two sets of weights are independent when the sum of the result of multiplying their corresponding weights equals zero.