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Exploration of the mechanisms underlying the ISPC effect: Evidence from behavioral and neuroimaging data

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ABSTRACT

The item-specific proportion congruent (ISPC) effect in a Stroop task – the observation of reduced interference for color words mostly presented in an incongruent color – has attracted growing interest since the original study by Jacoby, Lindsay, and Hessels [(2003) *Psychonomic Bulletin & Review*, *10*(3), 638–644]. Two mechanisms have been proposed to explain the effect: associative learning of contingencies and item-specific control through word reading modulation. Both interpretations have received empirical support from behavioral data. Therefore, the aim of this study was to investigate the responsible mechanisms of the ISPC effect with the classic two-item sets design using fMRI. Results showed that the ISPC effect is associated with increased activity in the anterior cingulate (ACC), dorsolateral prefrontal (DLPFC), and inferior and superior parietal cortex. Importantly, behavioral and fMRI analyses specifically addressing the respective contribution of associative learning and item-specific control mechanisms brought support for the contingency learning account of the ISPC effect. Results are discussed in reference to task and procedure characteristics that may influence the extent to which item-specific control and/or contingency learning contribute to the ISPC effect.

1. Introduction

Cognitive control refers to our ability to flexibly adjust our behavior depending on situational demands and changes in the environment. Cognitive control processes are typically assumed to be involved in situations where we have to restrain a predominant or instantaneous response in order to promote a more appropriate but less obvious and salient response. One of the most widely used paradigms in the study of cognitive control is the classic Stroop task (Stroop, 1935). In common variants of this task, participants must indicate the color that a word is printed in, while ignoring the meaning of the word. In incongruent trials, there is a mismatch between the color of the stimulus and the color word, such as the word *red* printed in green ink. Such stimuli require participants to select between competing naming and reading responses, unlike congruent stimuli such as the word *red* printed in red ink.

Different effects have been associated with the Stroop task. First of all, the interference effect consists in slower or less accurate responses for incongruent items than for congruent or neutral items. Interestingly, despite the low complexity of task instructions, the interference effect is a very robust phenomenon observed in hundreds of studies (MacLeod, 1991); it is explained by the automaticity and speed of the reading process once it has been fully acquired (Cohen, Dunbar, & McClelland, 1990; MacLeod & MacDonald, 2000). The facilitation effect, on the other hand, corresponds to faster or more accurate responses for words printed in a congruent color than for neutral items. As with the interference effect, facilitation occurs when participants rely on the well-practiced word reading process rather than on color naming (Brown, 2011; MacLeod & MacDonald, 2000). Together, interference from incongruent trials and facilitation from congruent trials represent the Stroop effect. Finally, other effects have also been associated with the Stroop task in the literature, namely the proportion congruent effect and the item specific proportion congruent (ISPC) effect, which will be discussed in the following sections.

1.1. The proportion congruent effect

The proportion congruent effect reflects the observation of smaller interference and facilitation effects in tasks characterized by the presentation of mainly incongruent items (e.g., Logan &

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Zbrodoff, 1979, 1998; Lowe & Mitterer, 1982). This effect has traditionally been studied at a global or list-wide level by comparing performance on congruent and incongruent blocks, namely blocks containing a majority of congruent or incongruent items, respectively (Bélanger, Belleville, & Gauthier, 2010; Kane & Engle, 2003). The standard interpretation of this phenomenon postulates that the inhibition of the word reading process varies depending on task context (e.g., Lindsay & Jacoby, 1994; Lowe & Mitterer, 1982), with a decreased influence of the word reading process for all the items (congruent and incongruent) presented during mostly incongruent blocks compared to mostly congruent blocks.

The dual mechanisms of control model (DMC; Braver, 2012; Braver, Gray, & Burgess, 2007; De Pisapia & Braver, 2006) explains the modulation of word reading according to task context by proposing the existence of two separate cognitive control mechanisms. In situations of high interference (when mainly incongruent items are presented), subjects would adopt a proactive strategy, which is an anticipatory and sustained form of attention, where goal-relevant information is highly activated (i.e., naming colors rather than reading words). Conversely, in a situation where interference is less frequent, participants would adopt a reactive control strategy, which consists in a late correction strategy, where attentional control is recruited only when needed, such as after the occurrence of an interfering item in a block where interference is rare.

1.2. The item-specific proportion congruent (ISPC) effect

In the last decade, the proportion congruent effect has also been observed at a more local level, when specific stimuli, rather than blocks of stimuli, are associated with high or low conflict (e.g., the stimulus *red* appearing in red ink 20% vs. 80% of the time). Again, smaller interference and facilitation effects for color words that were mainly presented in an incongruent color compared to color words usually presented in a congruent way have been reported (Bugg, Jacoby, & Toth, 2008; Jacoby et al., 2003).

In their original study, Jacoby, Lindsay, and Hessels (2003) noted that two dissociable interpretations could account for the ISPC effect First, the modulation interpretation (modulation or item-specific control hypothesis) considers that cognitive control might prevent full reading of words just after stimulus presentation. Specifically, as proposed by Bugg, Jacoby and Chanani (2011), Jacoby et al. (2003), Jacoby, McElree and Trainham, (1999), a word-reading filter would decrease the activation of irrelevant word dimensions as soon as the item is identified with a high probability of being incongruent. As a consequence, word reading processes would have a decreased influence on the response to provide. Second, an associative mechanism (associative learning or contingency hypothesis) could intervene, whereby participants would rapidly learn the stimulus–response (S–R) associations specific to each item (e.g., the word *red* is often presented in red, whereas the word *blue* is often presented in green). This color-word association would be the main determinant of the response (Schmidt, Crump, Cheesman, & Besner, 2007), independently of any processes (e.g., inhibitory processes) controlling the contribution of word reading.

Importantly, in Schmidt and Besner's (2008) view, the interpretation of the ISPC effect in terms of cognitive control is due to a general confound in the literature between proportion congruency (proportion of congruent items within a condition) and contingency (degree of S–R association for a given item). More specifically, this confound comes from classically comparing high- vs. low-contingency trials within the same proportion congruence condition (e.g., high-contingency congruent items with low-contingency incongruent items in the high proportion congruent condition) rather than directly comparing equivalent contingency trials (e.g., high-contingency congruent trials from the high proportion congruent condition with high-contingency incongruent trials from the low proportion congruent condition, and similarly for low-contingency trials). In their reanalysis of the data from Jacoby et al. (2003), Schmidt and Besner (2008) neutralized that confound by reorganizing the data and conducting a contingency by item type (or congruency) analysis. According to the authors, both the contingency and modulation hypotheses predict a main effect of trial type (congruent, incongruent), with longer reaction times for incongruent trials, and a main effect of contingency (high, low), with longer reaction times for low contingency trials. However, they differ concerning the interaction between these factors. Within the contingency hypothesis, it is assumed that the Stroop effect and the contingency effect act independently (i.e., the difference between congruent and incongruent trials would not be expected to vary by contingency). Within the modulation hypothesis, "incongruent trials should be more affected by attention, given that the majority of the Stroop effect is due to interference, with little or no facilitation from congruent trials" (Schmidt & Besner, 2008, p. 516). Hence, this interaction is predicted, with a smaller Stroop effect for high than low contingency items, if attentional control mechanisms are selectively engaged to override word reading in the case of high contingency incongruent words. In that regard, the results of that reanalysis showed an absence of interaction, indicating that contingency information was enough to explain the ISPC effect.

1.3. Item-specific control mechanisms and proportion congruent effect at the list level

Importantly, some authors have recently proposed that item-specific control mechanisms, rather than variations in control strategy at the list-wide level, may also account for the proportion congruent effect at the global or list level (Blais & Bunge, 2010; Blais, Robidoux, Risko, & Besner, 2007; Bugg et al., 2008). Indeed, in typical list-wide proportion congruency experiments, variations in list-wide proportion congruency are confounded with variations in item-specific proportion congruency. For example, in a mostly incongruent bloc (80% of incongruent trials), all the items of the stimulus set (e.g., the words *Black*, *Blue*, *Green*, and *Red*) appear in an incongruent form for 80% of the trials and in a congruent form for 20% of the trials. Hence, a control mechanism acting at the item-specific level can account alone for the list-wide proportion congruency effect. In that context, Bugg et al. (2008) recently unconfounded list-wide and item-specific proportion congruency and obtained data supporting the hypothesis that list-wide effects can be accounted for by item-specific mechanisms (see also Blais & Bunge, 2010, for similar findings). However, other recent studies provided evidence of the involvement of list-level control mechanisms when item-specific influences were controlled for (Bugg & Chanani, 2011; Bugg, McDaniel, Scullin, & Braver, 2011; Hutchison, 2011). Hence, even if item-specific control mechanisms may be partly responsible of the list-wide proportion congruency effect, it seems too early to dismiss any contribution of list-wide control mechanisms modulating the influence of word reading processes.

1.4. Neuroimaging of proportion congruent and ISPC effects in the Stroop task

Studies that have attempted to determine the brain areas associated with interference resolution in the Stroop task have consistently reported the involvement of a large fronto-parietal network involving the dorsolateral prefrontal cortex (DLPFC),