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Properties of context-driven control revealed through the analysis of sequential congruency effects

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ABSTRACT

The context specific proportion congruent (CSPC) effect refers to the reduction in the size of the congruency effect at locations with a high proportion of incongruent trials compared to locations with a high proportion of congruent trials. The CSPC effect is commonly taken as evidence for context-driven modulation of cognitive control. Current models of context-driven control suggest that variations in the efficiency of control across locations are due to variations in the occurrence of conflict across locations (context). Moreover, these models predict that control settings are updated on a trial-to-trial basis. In Experiment 1, we investigated this prediction. If variations in conflict drive variations in the efficiency of control, and these location-based control settings are updated on each trial, then the occurrence of conflict at one location should lead to more efficient processing when the location repeats, but not when the location switches. Consistent with this prediction, we observed a sequential congruency effect when the location repeats, but not when the location switches. In Experiment 2, we looked for evidence of sequential congruency effects within and between locations in a manipulation in which an equal proportion of congruent and incongruent trials appear at each location. In contrast to the results of Experiment 1, we observed sequential congruency effects both when location repeated and when location switched. Thus, location appears to be a salient dimension on which to implement control settings when it is used in conjunction with variations in the proportion of congruent and incongruent trials.

Cognitive control in selective attention is commonly studied using interference tasks, of which the paradigmatic example is the Stroop task (MacLeod, 1991). In Stroop, participants respond to stimuli consisting of color words (e.g. BLUE) presented in a color (e.g. blue or green) and are instructed to name the color in which the word appears. The color can be consistent (congruent) or inconsistent (incongruent) with the meaning of the word. Performance is generally slower and less accurate on incongruent relative to congruent trials, suggesting an inability to fully inhibit processing of the word dimension (MacLeod, 1991).

To measure how successful participants are at selecting the weaker (but task-relevant) color dimension over the stronger (but task-irrelevant) word dimension, response times (RTs) for incongruent and congruent trials can be compared. The difference in RT for incongruent minus congruent trials is referred to as the congruency effect and the size of this effect is used as a measure of the efficiency of cognitive control. Specifically, large congruency effects are associated with less efficient control and small congruency effects are associated with more efficient control (Cohen, Dunbar, & McClelland, 1990; Verguts & Notebaert, 2009). In an effort to better understand the mechanisms that support the implementation and maintenance of cognitive control, recent work has sought to identify aspects of stimulus experience that lead to changes in the efficiency of control.

The conflict monitoring framework provides one such mechanism for how stimulus experience influences the implementation and maintenance of cognitive control (Botvinick et al., 2001). According to this framework, the occurrence of conflict in processing serves as information that can be used to monitor and adjust cognitive control processes in order to avoid conflict in the future. When an individual is presented with a stimulus that requires a single response, conflict occurs when multiple responses are active. The experience of conflict is taken as evidence for inadequate control, and as a result, signals the need to tighten control on upcoming trials. In Stroop, conflict is typically greatest on incongruent trials. Consistent with conflict monitoring, the size of the congruency effect is reduced following incongruent relative to congruent trials (Kerns et al., 2004) and this *sequential congruency*[1] effect occurs in the absence of specific stimulus overlap from trial N to

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[1] This effect is alternatively referred to as the conflict adaptation (Botvinick, Braver, Barch, Carter, & Cohen, 2001), Gratton (Desender, Van Opstal, & Van den Bussche, 2014), or congruency sequence effect (Weissman, Hawks, & Egner, 2016).

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Table 1
Representative stimulus list for an item level manipulation.
(Adapted from Jacoby et al., 2003.)

Item type	Word	Color			
		Blue	Green	Red	Yellow
Mostly congruent	BLUE	36	12		
	GREEN	12	36		
Mostly incongruent	RED			12	36
	YELLOW			36	12

trial N + 1 (Desender et al., 2014; Kerns et al., 2004; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; but see: Weissman et al., 2016). In this way, the occurrence of conflict in processing appears to lead to an adjustment in the relative contribution of the color and word dimensions in producing a response.

A challenge to the conflict monitoring account comes from the results of *item level* manipulations. In item level manipulations, participants encounter stimulus lists in which certain words and colors appear most frequently as incongruent trials (mostly incongruent items) while other words and colors appear most frequently as congruent trials (mostly congruent items). Importantly, these lists contain an equal proportion of incongruent and congruent trials overall, ensuring that the prior trial will be incongruent or congruent with an equal probability (see Table 1) (Jacoby, Lindsay, & Hessels, 2003). There are two important outcomes of item level manipulations. First, mostly incongruent items are associated with smaller congruency effects compared to mostly congruent items, a finding referred to as the item specific proportion congruence (ISPC) effect. Second, sequential congruency effects are absent between item type but can be observed within individual words. That is, the occurrence of an incongruent trial of a particular word is associated with a reduced congruency effect when that same word is encountered several trials later (Hutcheon & Spieler, 2014). These results contrast with the original instantiation of conflict monitoring and imply that under certain conditions, the occurrence of conflict in processing may serve to bias performance at the level of stimulus features (e.g. specific words) not the level of stimulus dimensions.

Two competing accounts have been put forth to explain the ISPC effect: item level control and contingency learning. Item level control accounts argue that in item level manipulations control is implemented at the feature level (e.g. if the word is RED, inhibit processing of the word dimension) rather than the dimension level (e.g. inhibit processing of the word dimension).[2] These accounts borrow the basic structure of conflict monitoring but move the level at which control is implemented. The occurrence of conflict for a particular feature (e.g. the word RED) leads to a tightening of control for that feature but not for other features (e.g. the word BLUE) (Blais, Robidoux, Risko, & Besner, 2007; Blais & Verguts, 2012; Verguts & Notebaert, 2008, 2009). The ISPC effect emerges because the frequent occurrence of conflict leads to the frequent tightening of control for mostly incongruent items and the infrequent occurrence of conflict leads to the infrequent tightening of control for mostly congruent items (Blais et al., 2007; Bugg & Crump, 2012; Verguts & Notebaert, 2008).

Jacoby et al. (2003) were the first to acknowledge that contingency learning could be viewed as an alternative explanation for the ISPC effect. For example, from the stimulus list presented in Table 1, if a participant knows the word is BLUE, they know the likely response is "Blue". When presented with a stimulus containing the word BLUE, the use of word information to predict the likely response would lead to relatively fast congruent trials and relatively slow incongruent trials. In contrast, if an individual knows the word is RED, they know the likely response is "Yellow". When presented with a stimulus containing the word RED, the use of word information to predict the likely response would lead to relatively fast incongruent trials and relatively slow congruent trials (Schmidt & Besner, 2008). Therefore, variations in the size of the congruency effect observed in item level manipulations may be driven not by variations in the occurrence of conflict across locations but by the predictive relationships between specific words and specific responses (Schmidt, 2013). Bugg and colleagues have recently proposed the dual item-specific mechanisms account which predicts contingency learning under certain conditions and control under others in item-level manipulations (Bugg, 2015; Bugg & Hutchison, 2013).

Fortunately, it is possible to remove the predictive relationship between specific words and responses endemic to item level manipulations. In *context level* manipulations, the proportion of congruent and incongruent trials varies along an additional irrelevant dimension such as spatial location. Participants are presented with a word at fixation immediately followed by a color patch either above or below fixation and are instructed to ignore the word and to name the color of the color patch. All colors (responses) are equally likely to occur at each location and are equally likely to be presented with each word, but the probability of encountering a congruent or incongruent color patch differs by location. At one location, the majority of color patches are associated with incongruent trials, and at the other location the majority of color patches are associated with congruent trials (Bugg, 2014; Crump et al., 2006). The irrelevant location dimension is uninformative about the likely response, but the probability of conflict is different at the two locations (see Table 2). Consistent with a control account, a context specific proportion congruent (CSPC) effect is observed in which the size of the congruency effect is reduced at mostly incongruent relative to mostly congruent locations (Bugg, 2014; Crump et al., 2006; King, Korb, & Egner, 2012). The CSPC effect has been extended to other irrelevant contextual features including color (Vietze & Wendt, 2009), font type (Bugg, Jacoby, & Toth, 2008), gender (Cañadas, Rodríguez-Bailón, Milliken, & Lupiáñez, 2013) and primes (Heinemann, Kunde, & Kiesel, 2009; Reuss, Desender, Kiesel, & Kunde, 2014), and together these findings appear to reflect a more general *context-driven* control (Crump, 2016).

Although the use of a context-level manipulation removes the predictive relationship between words and responses seen in a typical ISPC manipulation, it is still the case that participants could be using information about the combination of a specific location and a specific word to predict the likely response (Schmidt, 2013). This more complex contingency learning would similarly predict a reduction in the size of the congruency effect at mostly incongruent compared to mostly congruent locations in a context-level manipulation. However, the CSPC effect has also been found in context-manipulations that control for location-word contingencies (Crump & Milliken, 2009). In context-level transfer manipulations, two sets of items are used. One set, referred to as the context set, contains stimuli that frequently appear as incongruent at one location and frequently appear as congruent at the other location. The other set, referred to as the transfer set, contains stimuli that are equally likely to appear as congruent and incongruent trials at each location. In this way, the overall proportion of congruent and incongruent trials varies as a function of location but specific words and color patches are equally likely to occur as congruent and incongruent trials at each location. Consistent with a control account, a CSPC effect is observed for the unbiased transfer set (Crump, Brosowsky, & Milliken, 2017; Crump & Milliken, 2009, but see Hutcheon & Spieler, 2017).

In order for contingency learning to account for evidence of context-driven control such as the CSPC and CSPC transfer effect, it has been argued that individuals use the combination of the irrelevant location dimension, the irrelevant word dimension, and the pace of previous responding to increase or decrease the response threshold on the current trial. At mostly congruent locations this threshold is low and at

[2] In item level manipulations stimulus features are colors and words. However, since word information is available early in processing (MacLeod, 1991), it is generally assumed that word is the feature on which control operates (Bugg & Crump, 2012; Crump, Gong, & Milliken, 2006).