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The congruency sequence effect emerges when the distracter precedes the target

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ABSTRACT

The congruency effect in distracter interference tasks is typically smaller when the previous trial was incongruent as compared to congruent, suggesting the operation of a control process that minimizes the influence of irrelevant stimuli on behavior. However, both the conditions under which this congruency sequence effect (CSE) can be most easily observed without the typical learning and memory confounds, and the control process underlying it, remain controversial. We therefore tested a recent hypothesis that the CSE is most easily observed without the typical confounds when the distracter is processed before the target. In line with this "distracter head start" hypothesis, in Experiments 1 and 2 the CSE was larger when the distracter appeared before, relative to with, the target. Further, in Experiment 3, we observed a negative congruency effect after incongruent trials when a long interval separated the distracter from the target, consistent with a modulation of the response engendered by the distracter but not with a shift of attention toward the target. These findings reveal an important determinant of CSE magnitude when the typical learning and memory confounds are absent and new insights into the nature of control processes that contribute to this phenomenon.

1. Introduction

Researchers often employ distracter interference tasks to investigate how selective attention minimizes distraction from irrelevant stimuli. In such tasks, study participants are instructed to identify a target stimulus while ignoring one or more distracters. For example, in the classic flanker task, participants are asked to identify a central target letter (e.g., H or S) that is positioned between two identical distracters (Eriksen & Eriksen, 1974). In congruent trials, the target and distracter letters match (HHH or SSS) and therefore engender the same response. In incongruent trials, the target and distracter letters differ (HSH or SHS) and therefore engender conflicting responses. Across a wide variety of distracter interference tasks (e.g., Stroop, flanker, and Simon), performance is slower and less accurate in incongruent than in congruent trials (MacLeod, 1991). This phenomenon, known as the congruency effect, indicates that selective attention often does not eliminate distraction from irrelevant stimuli.

The efficiency of selective attention, however, appears to vary considerably from one moment to the next. For example, the congruency effect is typically smaller when the previous trial was incongruent as compared to congruent. This *congruency sequence effect (CSE)* has been observed in numerous distracter interference tasks, including the flanker task (Gratton, Coles, & Donchin, 1992), the Stroop task (Kerns et al., 2004), and the Simon task (Sturmer, Leuthold, Soetens, Schroter, & Sommer, 2002). There is an ongoing debate, though, about whether the CSE is driven by (1) a cognitive control process that minimizes the influence of irrelevant stimuli or (2) learning and memory processes that are confounded with the CSE in the overwhelming majority of distracter interference tasks (Egner, 2007; Schmidt, 2013). We begin by describing two cognitive control accounts of the CSE – the *attentional shift* account and the *response modulation* account – before moving on to discuss learning and memory accounts and a recent hybrid cognitive control/learning memory account.

1.1. Cognitive control accounts

The *attentional shift* account posits that the CSE reflects a control process that changes the distribution of attention to distracter and target stimuli as a function of whether the previous trial was incongruent or congruent. Four distinct variants of this account appear most prevalent in the literature. First, the perceptual expectation hypothesis posits that participants expect the forthcoming trial to resemble the previous trial, and adapt their attentional strategy accordingly. For instance, in the flanker task, the focus of spatial attention would widen after a congruent trial to include both the target and the distracter, but would narrow after an incongruent trial to include the target but exclude distracter (Gratton et al., 1992). Second, the conflict monitoring hypothesis asserts that participants pay more attention to the target and/or less attention

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to the distracter in the current trial when the previous trial engenders high levels of response conflict (e.g., incongruent trials) as compared to low levels of response conflict (e.g., congruent trials) (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Third, in tasks wherein the distracter temporally precedes the target, the temporal attention hypothesis posits that, via a change in the task representation, participants allocate more or less attention to the moment in time at which the distracter appears, respectively, depending on whether the previous trial was congruent or incongruent (Hazeltine, Lightman, Schwarb, & Schumacher, 2011). Fourth, the negative affect hypothesis posits that participants experience the effort associated with processing an incongruent stimulus in the previous trial as aversive (cf. Botvinick, 2007), which leads them, in a form of avoidance learning, to increase attention to the target and/or decrease attention to the distracter in the current trial, thereby avoiding the re-occurrence of negative affect (Dreisbach & Fischer, 2012). Critically, all four variants of the *attentional shift* account posit that the CSE indexes a relative increase of attention toward the target and away from the distracter when the previous trial was incongruent relative to congruent.

The *response modulation* account posits that the CSE indexes a control process that modulates the response engendered by the distracter when the distracter is able to activate a response before the target. There are two distinct variants of this account. First, the activation–suppression hypothesis posits a control mechanism that inhibits the response evoked by the distracter. To account for the CSE, the model assumes that this mechanism is more efficient on the current trial when it had to be engaged on the previous trial; thus, the distracter response is inhibited more effectively before the target is identified when the previous trial was incongruent as compared to congruent (Ridderinkhof, 2002a). Second, in two-alternative-forced-choice (2-AFC) tasks, the response expectation hypothesis posits that participants "pre-activate" the response signaled by the distracter if the previous trial was congruent, leading to a relatively large congruency effect, or the opposite response if the previous trial was incongruent, leading to a relatively small congruency effect (Logan, 1985). While this hypothesis was originally formulated in the context of biased proportions of congruent and incongruent trials (Logan & Zbrodoff, 1979), such a strategy may occur even when congruent and incongruent stimuli appear equally often, because participants appear to expect congruency repetitions across consecutive trials more than they expect congruency alternations (Duthoo, Wuhr, & Notebaert, 2013; Gratton et al., 1992). In sum, the *response modulation* account posits that the CSE occurs when the distracter is processed before the target, such that control processes have time to modulate the distracter response before the target is identified.

1.2. Learning and memory accounts

In contrast to the cognitive control accounts of the CSE above, learning and memory accounts posit that the CSE reflects learning and memory processes that are confounded with congruency sequence in the vast majority of distracter interference tasks. There are two main variants of the learning and memory account. First, the *feature integration hypothesis* posits that the CSE indexes the influence of stimulus and/or response feature repetitions that are typically confounded with congruency sequence in distracter interference tasks (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003). Specifically, especially in distracter interference tasks with small stimulus sets, congruency repetitions across consecutive trials (i.e., congruent–congruent [cC] and incongruent–incongruent [iI] trials) are composed of either complete stimulus and response feature repetitions or complete stimulus and response feature alternations. In contrast, congruency alternations across consecutive trials (i.e., congruent–incongruent [cI] and incongruent–congruent [iC] trials) consist entirely of "partial repetitions", wherein some stimulus and response features change while others remain the same. Since it is well-established that partial repetitions evoke a form of memory-retrieval conflict, and are associated with slower and more error-prone responses (Hommel, 1998), the *feature integration hypothesis* posits that the CSE indexes different distributions of complete feature repetitions, complete feature alternations, and partial feature repetitions across the four possible congruency sequences (Hommel et al., 2004).

Second, in tasks with more than two stimuli and responses, the *contingency learning hypothesis* posits that the CSE indexes a stronger association between each distracter and its congruent response than between each distracter and any of the multiple possible incongruent responses (Schmidt & De Houwer, 2011). This strengthened association, or "high contingency", occurs because each distracter is presented more frequently with the congruent target than with each possible incongruent target, a procedure that is frequently employed to equate the number of congruent and incongruent trials (Schmidt, 2013). Since responding in a high contingency (congruent) trial occurs more quickly following a previous high contingency trial, it has been suggested that the CSE reflects a contingency (rather than congruency) sequence effect (Schmidt & De Houwer, 2011). Critically, in line with the learning and memory account, the CSE often vanishes in the manual Stroop, flanker, and Simon tasks when feature integration and contingency learning confounds are removed (Mordkoff, 2012; Schmidt & De Houwer, 2011). Thus, some researchers have suggested that the CSE reflects nothing more than learning and memory confounds (Mayr et al., 2003; Schmidt, 2013; Schmidt & De Houwer, 2011).

1.3. Hybrid accounts

Some researchers have suggested that cognitive control and learning and memory processes interact to engender a CSE. For example, the *adaptation by binding* model posits that response conflict in incongruent trials leads a performance-monitoring system housed in the posterior medial frontal cortex (pMFC) to increase arousal via interactions with the locus coeruleus (Verguts & Notebaert, 2008). This increase in arousal strengthens associations between task-relevant stimulus features and the current task representation, which reduces the congruency effect in the next trial by enabling the correct response in incongruent trials to be more quickly retrieved. In more recent versions of the model (Blais & Verguts, 2012), the association between a given stimulus feature and the current task representation is strengthened in incongruent trials to a greater degree when the stimulus was more recently presented (and thus has a higher level of activation) than when the stimulus was less recently presented (and thus has a lower level of activation). This assumption fits with several recent findings indicating that the CSE is reduced or eliminated when the current trial contains no feature repetitions from the previous trial (Blais & Verguts, 2012; Mayr et al., 2003; Mordkoff, 2012; Schmidt & De Houwer, 2011). Such findings clearly indicate that learning and memory processes contribute to the CSE, either independently or via interactions with cognitive control.

1.4. Recent support for an independent contribution of cognitive control to the CSE

Consistent with accounts in which cognitive control is able to contribute to the CSE independently of learning and memory processes, we recently reported that the CSE *can* be observed without feature integration or contingency learning confounds (Schmidt & Weissman, 2014). For example, in each trial of a prime–probe word task, three vertically-stacked distractor words (left, right, up, or down) were followed by a target word (left, right, up, or down). Participants were asked to identify the direction indicted by the target word (e.g., left) as quickly as possible without making mistakes by pressing one of four spatially-compatible keys. To prevent stimulus repetitions in consecutive trials, we divided the 4-AFC prime–probe word task into a pair of 2-AFC choice tasks – a "left–right" task and an "up–down" task – each of which contained two congruent stimuli and two incongruent stimuli (Mayr et al., 2003). We then alternated between these tasks on every trial (Jimenez & Mendez, 2013; Mayr et al., 2003). To prevent response repetitions in consecutive trials, participants responded