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Conflict monitoring and feature overlap: Two sources of sequential modulations

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Recent findings demonstrating that the Simon effect diminishes when the preceding trial is a noncorresponding trial led researchers to develop two alternative accounts. The conflict monitoring account argues that the automatic activation from stimulus location information is under the regulation of a control mechanism, which adjusts the level of activation depending on conflict in the preceding trial. In contrast, the feature integration account holds that sequential modulations of the Simon effect can be attributed to the integration of stimulus and response features into event files. Previous research demonstrated a potential contribution to sequential modulations from both mechanisms. We use a four-choice task to extend these findings and to investigate the exact nature of the feature overlap effects. Both conflict monitoring and feature overlap effects were found to contribute to sequential modulations. However, the feature overlap effects did not conform to predictions of the feature integration account. We argue that the feature overlap effects are accounted for better by strategic shortcuts in response selection.

To flexibly guide behavior, the human cognitive system draws on a tremendous range of information in the environment. Adaptive control processes must dynamically select and control the weightings of relevant inputs in an efficient and goal-directed way. Consider a task in which spatially defined responses (e.g., "left" vs. "right") are made to nonspatial attributes of the stimuli (e.g., their color). The stimuli occupy distinct locations that correspond with the response locations, but these stimulus locations are irrelevant to the task. Nonetheless, when the stimulus location corresponds with the correct response location, responses are faster than when the stimulus location and the response location do not correspond. This effect of stimulus location on reaction time (RT) is called the *Simon effect* (Simon & Rudell, 1967).

The Simon effect is generally explained in the context of a dual-route model of response selection (Kornblum, Hasbroucq, & Osman, 1990). According to this account, two processing routes determine which responses are selected. A controlled route translates the relevant stimulus feature into the response according to the arbitrary mapping defined by the task instructions. This flexible, rule-based route is complemented by a direct or automatic route that activates response codes on the basis of stimulus features that overlap with response features along some dimension. In the case of the Simon effect, the direct route activates the corresponding response code on the basis of the stimulus location (e.g., a stimulus on the left side activates the "left" response). When the response code activated by both routes is the same (i.e., when the trial is a corresponding trial), response selection is facilitated, whereas activation of different codes (on noncorresponding trials) leads to conflict, and response selection is slowed.

A critical aspect of the Simon effect is that its magnitude depends on the correspondence of the previous trial. That is, a number of studies have found that the Simon effect is greatly reduced or even reversed (RTs on the noncorresponding trials being shorter than RTs on the corresponding trials) on trials following noncorresponding trials (Hommel, Proctor, & Vu, 2004; Notebaert, Soetens, & Melis, 2001; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Valle-Inclán, Hackley, & de Labra, 2002).

Two Accounts of Sequential Effects

To account for sequential modulations, researchers have proposed a conflict monitoring hypothesis. According to this view, conflict between competing responses drives the demand for controlled processing, and the control mechanisms use this information. Botvinick, Braver, Barch, Carter, and Cohen (2001) developed a computational model describing how conflict could engage increased control. On noncorresponding trials, the level of conflict between the competing response codes is detected by a conflict-monitoring mechanism, which activates control processes. The result is that, on the next trial, the weight of the direct route is attenuated, which decreases response competition (see also Stürmer et al., 2002). Note that this account significantly modifies the assumption of the "automatic" direct route of the dual-route model (Kornblum et al., 1990) by making it subject to control.

Although the conflict monitoring hypothesis is supported by electrophysiological (Stürmer et al., 2002), and

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neuroimaging (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Carter et al., 1998) evidence, some researchers have challenged the notion that the sequential modulations must be attributed to such a control mechanism (Mayr, Awh, & Laurey, 2003). In a two-choice Simon task, there are three critical features, each with two values: the stimulus location, the relevant stimulus feature, and the response location. Because the response location is determined by the relevant stimulus feature, these two features are perfectly correlated, and integration effects can be seen as the two-way interaction between repetition of stimulus location and repetition of response location. Sequences of two corresponding trials (Co–Co) or two noncorresponding trials (Nc–Nc) are always either complete repetitions (in which all three features repeat) or complete changes (in which all three features change). However, sequences of one corresponding trial and one noncorresponding trial (Co–Nc or Nc–Co) are always partial repetitions, in which one or two stimulus–response (S–R) features repeat but the others change.

Hommel et al. (2004) showed that partial repetitions incur a significantly greater cost on RT than do complete changes and complete repetitions. This pattern of *feature overlap effects* is consistent with the feature integration account (Hommel, 1998, 2004) and can account for sequential modulations. According to the feature integration account, sequential effects are due to an additional mechanism that is responsible for building integrated representations of S–R episodes, or *event files*. This feature integration mechanism binds features of the stimulus and features of the response on a given trial into an event file, which remains integrated at least until the next trial. On the next trial, if some of the S–R features repeat but others change (e.g., the same stimulus, but at the opposite location), the repeating features activate the remaining (nonrepeating) features in the event files, which creates stimulus and/or response conflict. Consequently, RT on *partial-repetition* trials is lengthened. On the other hand, if all of the features repeat (complete repetitions) or change (complete change) from one trial to the next, there is no interference from the previous event file, and performance is faster.

As noted above, the partial-repetition trials are exclusively Co–Nc and Nc–Co sequences. This increases the difference in RT between Co–Co and Co–Nc trials (i.e., the Simon effect after corresponding trials) and decreases the differences between Nc–Co and Nc–Nc trials (i.e., the Simon effect after noncorresponding trials). Thus, because complete-repetition and complete-change trials always consist of Co–Co and Nc–Nc sequences, the Simon effect is inflated after corresponding trials but decreases after noncorresponding trials. Therefore, the feature integration account is a viable account of the sequential modulations in the Simon effect (Notebaert et al., 2001).[1]

To dissociate the contributions of the two processes, Notebaert, Gevers, Verbruggen, and Liefooghe (2006) used a three-choice Stroop task with two different response–stimulus intervals (RSIs). They hypothesized that conflict monitoring would take time to exert its effect on performance on the subsequent trial because it was a "top-down" process. In contrast, feature integration, a "bottom-up" process, in their view, should show its effect independently of RSI. Consistent with these assumptions, they found that sequential modulations on complete-change trials depended on the RSI, with no sequential modulations at the short RSI but significant sequential modulations at the long RSI. Moreover, sequential modulations on the remaining trials were significant in both RSI conditions. Thus, the study showed that sequential modulations can result from both feature overlap effects and conflict monitoring, each making an independent contribution (see also Kerns et al., 2004; Wühr, 2005).

In attempts to dissociate the two processes, the general strategy has been to hold the type of repetition/change sequences constant (e.g., by isolating complete-change sequences) and look for the sequential modulations within this data set. This logic treats the feature integration hypothesis as a null hypothesis that is ruled out as the sole contributor to sequential modulations when sequential modulations are found in the particular subset of the data. However, the feature integration hypothesis is more than a null hypothesis; it makes distinct predictions about the feature overlap effects, which may or may not conform to these predictions. To our knowledge, this has been tested only with two-choice tasks (Hommel, 1998, 2005; Hommel & Colzato, 2004; Hommel et al., 2004).

However, a two-choice task might be a special case in that it affords strategies that might result in the pattern of feature overlap effects. For instance, Notebaert and Soetens (2003) argued that a change in the stimulus might result in a tendency to alternate the response, leading to a benefit for those trials, with both response and location alternating. In fact, this possibility is also mentioned by Hommel et al. (2004), who note that "the complete mismatch signals the alternative response" (p. 3). This strategic account is distinct from the feature integration process that they propose, because on complete-change trials no features on the current trial were activated on the previous trial (Hommel, 1998). The comparable benefit of complete repetitions over partial repetitions can then be explained either by a similar tendency to repeat when the stimulus changes, or by additive effects of repeating two features.

Critically, a strategy that confers a benefit for complete-change trials is quite plausible in a two-choice task but not in a task with more than two choices. When more than one alternative response could go with the salient change in the stimulus, the one-to-one correspondence between the change in the stimulus feature and the change in the response is eliminated. Consequently, the benefit of complete change should be abolished. To evaluate these predictions, we used a four-choice task to investigate conflict monitoring and feature integration as contributors to sequential modulations in the Simon effect. We focused on two critical issues.

First, we sought to examine whether the effects of feature overlap and conflict monitoring can be observed to be occurring simultaneously. Because complete-change trials in a four-choice task can constitute any of the four possible sequential pairings of corresponding and noncorresponding trials, it is possible to assess sequential modu-

lations free of feature overlap effects that can contaminate the effects of conflict monitoring. This logic can also be used to test the predictions of the feature integration account. Specifically, Nc–Nc sequences in the four-choice task can constitute any of the four classes of feature overlap (complete repetition, complete change, location repetition only, and response/shape repetition only). Because previous correspondence and current correspondence are held constant, the effects of feature overlap are uncontaminated by the effects of conflict monitoring.

Second, we wished to determine whether feature overlap effects result from the formation of event files. The event file account predicts that complete-repetition and complete-change sequences should be faster than partial-repetition sequences even for four-choice tasks (Hommel, 2004, 2005). This is because activating one feature in an event file should activate the other features in that event file, which should create interference in performance, since these features do not repeat. Alternatively, if the feature overlap effects are due to tendencies to repeat or to alternate responses with salient changes in the stimulus, we should see no difference between partial repetitions and complete changes.

To resolve the second issue, a critical confound has to be removed from the task. On some complete-change sequences, location of the stimulus on the previous trial corresponds with the current response. On other sequences, the response location from the previous trial may correspond with the current stimulus location. We term these trials *negative priming trials*. The possibility of negative priming is especially critical after Nc trials, because on Nc trials the interfering location information might be suppressed. Consequently, if the suppressed location corresponds with the next response, performance might be slowed, thus giving complete-change trials an additional disadvantage. The performance on complete-change trials is critical for a test of the feature integration account, so we must eliminate these trials as well, which can be done with a four-choice task (but not with a three-choice task).[2]

METHOD

Participants

Eighteen undergraduate students participated in the experiment in exchange for course credit. All had normal or corrected-to-normal vision and were right-handed.

Apparatus and Stimuli

The stimuli were presented on a 17-in. LCD monitor controlled by an IBM-compatible PC from a distance of approximately 50 cm. Four identical outline rectangles (boxes) were visible on the screen throughout the trial. The boxes were arranged in a row along the horizontal meridian of the screen. Each box subtended approximately 4.7º of visual angle vertically and 4.5º horizontally. The centers of the inner two boxes were 2.9º from the center of the screen. The centers of the outer two boxes were 8.6º from the center of the screen. The stimuli were colored squares that filled the boxes completely. The colors used in this experiment were red, green, blue, and yellow, and they mapped to four horizontally arranged keys of a custom-made keyboard, in the same order from left to right. The participants responded by pressing these four keys with the index, middle, ring, and small fingers of their right hands, respectively.

Procedure and Design

The participants completed a practice block with 32 trials followed by 12 test blocks of 97 trials. There are 16 possible color–location combinations in the four-choice task, four of which constitute corresponding trials. We equated the frequencies of corresponding and noncorresponding trials by tripling the likelihood of corresponding trials. We then generated two pseudorandomized lists of 576 (24 current trial types × 24 previous trial types) color–location combinations and divided each of the two lists into six lists of 96 combinations. The last combination from the previous list was repeated as the first combination in the following list (which was excluded from the analyses), so the final list of each block was 97 trials long, for a total of 577 trials.

Each trial began with a 500-msec foreperiod during which only the white boxes were visible. Next, a colored square appeared in one of the boxes. The color remained on the screen for 150 msec and was followed by a response interval of 1,850 msec, during which only the boxes were visible again. The participants were instructed to respond as quickly and accurately as possible. If the correct response was made, the next trial began after the response interval. If the participant did not respond or responded incorrectly, the response interval was followed by a 2-sec fixation screen, and a 500-msec tone was played to give feedback.

RESULTS

Accuracy

Overall accuracy in the task was 96%. Effects of correspondence and feature repetitions followed the same pattern for accuracy as for the RTs (see Tables 1 and 2).

Reaction Times

First trials of each block, trials with incorrect responses or with RTs more than 2.5 *SD*s from the mean RT for each participant, and trials immediately following incorrect trials were excluded from RT analyses (10.14% of trials). Table 1 summarizes the RT and accuracy data with respect to correspondence conditions. We conducted our analyses on data in three parts.

Distance effects. In a four-choice task, Nc trials might lead to different levels of performance depending on the distance between the stimulus location and the correct response location, which can be one, two, or three boxes apart. To assess the effects of distance, we conducted an ANOVA on the Nc trials. The effect of distance was highly significant [$F(2,34) = 23.63, p < .001$]. Follow-up t tests showed that RTs on Distance 3 trials were shorter than those on both Distance 1 and Distance 2 trials (ps $<$ .005), but Distance 1 and Distance 2 trials did not differ significantly [$t(17) = 1.77, p > .09$] (see Table 1). We don't have an explanation for why RTs on the Distance 3

Table 1
Mean Reaction Times (RTs, in Milliseconds) and Error Rates With Respect to Correspondence on Current Trial

Trial	RT	Error Rate
Corresponding	543	.02
Noncorresponding		
Distance 1	627	.06
Distance 2	635	.06
Distance 3	598	.04

trials are shorter than those on the other two Nc trials.[3] However, given that the correspondence effect is present at all distances, we collapsed all noncorresponding trials for the remaining analyses.

Conflict monitoring effects. A 2 × 2 ANOVA with the factors of correspondence on the previous trial and correspondence on the current trial yielded significant main effects of previous correspondence [$F(1,17) = 55.98$, $p < .0001$] and of current correspondence [$F(1,17) = 510.75$, $p < .0001$]. The interaction between the two factors was also highly significant [$F(1,17) = 94.73$, $p < .0001$]. Consistent with previous findings, the Simon effect was 99 msec after the corresponding trials and 60 msec after noncorresponding trials (Figure 1, left panel, and Table 2).

Next, we conducted a 2 × 2 ANOVA with the factors of previous correspondence and current correspondence within the complete-change trials. Because no features repeat on these trials, they are free of any overlap effects. We also excluded the negative priming trials to remove any confounding negative priming effect. That is, trials on which the previous location corresponded with the current target and those in which the previous target corresponded with the current location were also not included in the analysis. There was a significant effect of previous correspondence [$F(1,17) = 24.10$, $p < .0001$], a significant effect of current correspondence [$F(1,17) = 279.55$, $p < .0001$], and a significant interaction between the two [$F(1,17) = 8.28$, $p < .01$]. The Simon effect was 104 msec after corresponding trials and 87 msec after noncorresponding trials. The 17-msec magnitude of this effect is smaller than what has been reported in studies in which the effects of conflict and feature overlap are confounded (e.g., Hommel et al., 2004; Stürmer et al., 2002). The right panel of Figure 1 shows that, even when feature overlap is held constant, sequential modulations can be obtained. This is evidence for a control process that is responsible for sequential effects, because the sequential modulations seen here cannot be due to any feature overlap effects.

Feature overlap effects. A 2 × 2 ANOVA with the factors of location repetition (repetition vs. change) and response repetition was conducted with all trials included. The effect of location repetition was significant [$F(1,17) = 70.05$, $p < .0005$], as was the effect of response repetition [$F(1,17) = 184.33$, $p < .0005$]. The interaction between the two factors was also highly significant [$F(1,17) = 303.90$, $p < .0005$]. As can be seen in Table 3 and in the left panel of Figure 2, the pattern of feature overlap effects bears striking differences from the effects reported by Hommel et al. (2004) for two-choice tasks. In particular, not all partial-repetition trials seem to elicit longer RTs than complete-change trials. However, this discrepancy might be due to different proportions of corresponding and noncorresponding trials in different repetition conditions.

To assess feature overlap effects uncontaminated by conflict monitoring effects, we restricted the analysis to the Nc–Nc sequences. These sequences form the only subset of data that includes all types of feature overlap combinations with current and previous correspondence held constant. Therefore, they provide a test for the predictions of the feature integration account free from any confounding effects of correspondence. We also eliminated the negative priming trials from this subset of data, to remove any effect of negative priming.

A 2 × 2 ANOVA with location repetition and response repetition as factors revealed results consistent with the preceding analysis: There were significant effects of location repetition [$F(1,17) = 42.37$, $p < .0005$] and response repetition [$F(1,17) = 161.91$, $p < .0005$], but no significant interaction. Complete-repetition trials were fastest (503 msec), followed by response repetition–location

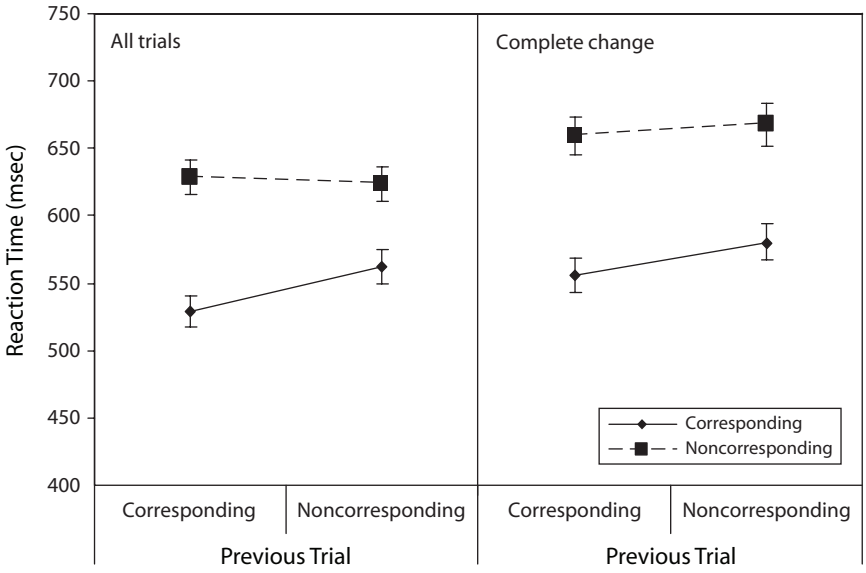

Figure 1. Sequential modulations of the Simon effect on all trials (left panel) and in complete-change sequences (right panel).

Table 2
Mean Reaction Times (RTs, in Milliseconds) and Error Rates With Respect to Previous Correspondence and Current Correspondence

Previous Trial	Current Trial	RT	Error Rate
Corresponding	Corresponding	529	.02
	Noncorresponding	628	.06
	Simon effect	99	.04
Noncorresponding	Corresponding	563	.02
	Noncorresponding	623	.05
	Simon effect	60	.03

change trials (537 msec), response change–location repetition trials (655 msec), and complete-change trials (668 msec). The right panel of Figure 2 shows that complete changes in this subset of the data are the slowest types of sequences. A *t* test indicated that RTs on complete-change trials are significantly longer than those on response change–location repetition trials [$t(17) < 2.18$, $p < .05$].

These results establish the presence of feature overlap effects. However, the pattern of feature overlap effects is different from that predicted by the feature integration hypothesis. According to the feature integration account (Hommel, 2004, 2005), partial-repetition trials should be slower than complete-change trials because of irrelevant activation from previously integrated features. After controlling for the effects of correspondence and negative priming, we fail to find evidence supporting the feature integration hypothesis. However, we see clear evidence that feature repetitions do affect performance, even when they are irrelevant to the task. This raises questions about the feature integration account as an explanation of feature overlap effects.

DISCUSSION

In the present study, we investigated two potential sources of sequential modulations of the Simon effect: conflict monitoring and feature integration. By examining complete-change trials only, we found significant sequential modulations of the Simon effect, which provide evidence that feature overlap effects cannot be the only contributors to sequential modulations. Furthermore, we found significant feature overlap effects in Nc–Nc sequences, indicating that they indeed play a role in sequential modulations. These results support the view that both feature overlap and conflict monitoring play a role in the sequential modulations, and extend previous studies by showing the independent contributions of both factors in sequential modulations. Moreover, we show that feature overlap effects do not confirm the predictions of the feature integration account (Hommel, 2004, 2005). Rather, the feature overlap effects seem to resemble additive benefits of location and response repetition.

In principle, ruling out feature overlap as the sole contributor to sequential modulations does not require acceptance of the conflict monitoring account. Indeed, recently evidence has been reported that response conflict itself might not be sufficient to recruit control (Burle, Allain, Vidal, & Hasbroucq, 2005; Kunde, 2003). To the best of our knowledge, however, no alternative account has been proposed to replace conflict monitoring mechanisms. Furthermore, the insufficiency of response conflict does not totally invalidate the conflict monitoring account (see, e.g., Kunde, 2003). Therefore, conflict monitoring remains a plausible account for the sequential modulations.

In the four-choice task, the Simon effect was on the order of 100 msec, which is much larger than is reported for two-choice tasks. One possibility might be that the response selection process becomes less efficient in implementing the S–R rules with increasing response choices and, therefore, more susceptible to response interference. Another possibility is that the frequencies of the corresponding stimulus combinations were larger than those of individual noncorresponding combinations (although the overall proportion of corresponding trials was equivalent), which might lead one to expect those combinations. This, in turn, might have led to an increased Simon effect.

The present study also demonstrated that the effects of feature overlap are robust even when the effects of correspondence are held constant and negative priming trials are eliminated. Moreover, the pattern of feature overlap effects was different from that predicted by the feature integration account. The feature integration account holds that repeating features activate other nonrepeating features in the event files, which leads to interference from these now irrelevant features (Hommel, 1998, 2005; Hommel et al., 2004). Therefore, the feature integration account predicts that responses to partial repetitions will be slower than those to both complete changes and complete repetitions. The data, however, show that the partial repetitions did not lead to slower performance than the complete-change sequences. In fact, feature repetition effects were additive, and RTs on complete-change trials were significantly longer than those on location repetition/response change trials when any confounding effect of correspondence and negative priming was removed. This is inconsistent with the feature integration account.[4]

Why is the pattern of feature overlap effects so different from that in a two-choice task (see, e.g., Hommel, 1998)? As we noted in the introduction, one possibility is that feature overlap effects are not caused by event files but by strategies. For example, Notebaert and Soetens (2003) held that the complete-change benefit in a two-choice task could be explained by a strategy of changing the response with a change in the stimulus (see also Hommel et al., 2004). Such a strategy would only be plausible in a two-choice task, in which there is only one alternative response

Table 3
Mean Reaction Times (RTs, in Milliseconds) and Error Rates With Respect to the Repetition and Change of Location and Response From the Previous Trial to the Current Trial

Response	Location	RT	Error Rate
Repetition	Repetition	464	.02
	Change	529	.03
Change	Repetition	627	.05
	Change	607	.04

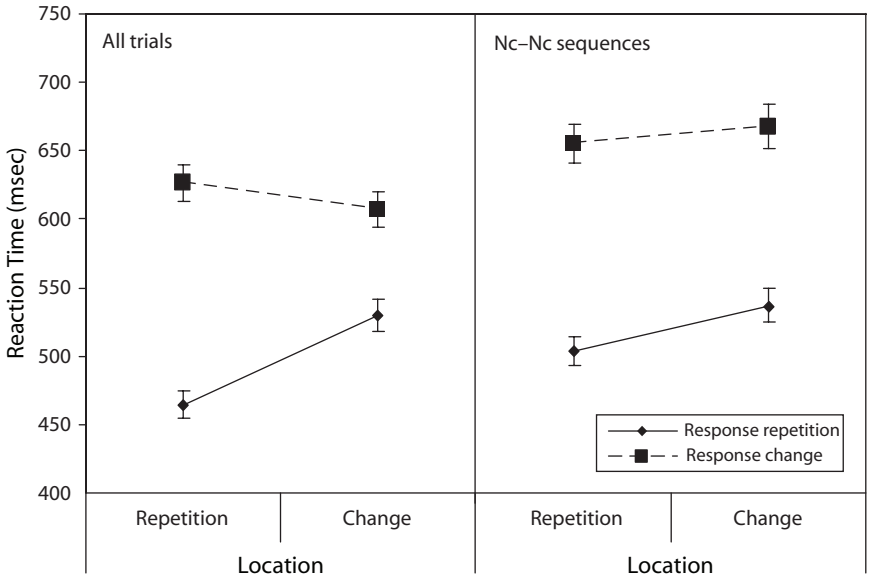

Figure 2. Feature overlap effects on all trials (left panel) and in Nc–Nc sequences without negative priming trials (right panel).

that can be signaled by a change in the stimulus. In a four-choice task, this strategy is not a feasible one, since there are three alternative responses that could be signaled by a change in the stimulus. Therefore, from this point of view, it is natural that complete alternations have no advantage over partial repetitions in a four-choice task. Such strategies need not rely on conscious processes, but can act as shortcuts (see Pashler & Baylis, 1991) that are set up early in the session and function in an automatic manner afterward. Whereas a variety of mechanisms may explain the observed pattern of feature overlap effects, the present findings show that four-choice tasks can provide powerful tools for assessing the sources of sequential modulations during conflict tasks.

AUTHOR NOTE

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NOTES

1. Although the two alternative hypotheses are reviewed in the context of the Simon effect, they have been applied to other conflict paradigms as well. For example, Gratton, Coles, and Donchin (1992) reported sequential modulations for the Flanker task and argued for a control mechanism similar to conflict monitoring.

2. We are grateful to Wim Notebaert and Ulrich Mayr for pointing out the advantages that the four-choice tasks hold over three-choice tasks in evaluation of sequential modulations (Kornblum & Stevens, 2002).

3. RTs on corresponding trials were significantly shorter than those for Distance 1 [$t(17) = 20.80$, $p < .00001$], Distance 2 [$t(17) = 20.23$, $p < .00001$], and Distance 3 [$t(17) = 7.71$, $p < .0001$]. A potentially interesting case in our task is the Distance 1 trials, in which the stimulus location and the response location are both on the same side (e.g., both are in the two locations on the right). These trials might be considered closer to corresponding trials and might not show a correspondence effect. However, when we isolated these Distance 1 trials and compared them to the corresponding trials, we found that their RTs were significantly longer (630 vs. 545 msec) [$t(17) = 22.38$, $p < .00001$].

4. In principle, one could argue that the complete repetition benefit is due to integrated event files. However, the individual features conferred independent repetition benefits, and there was no interaction between the factors indicating whether or not the features repeated. Thus, a more parsimonious account for the complete repetition benefit is that the repetition benefits have additive effects. Furthermore, with the exception of its earliest formulation (Hommel, 1998), the feature integration theory explicitly states that integrated event files create interference in the case of partial repetitions (see, e.g., Hommel et al., 2004, p. 4).

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