Psychological Research (2004) 68: 1–17
DOI 10.1007/s00426-003-0132-y

ORIGINAL ARTICLE

Bernhard Hommel · Robert W. Proctor
Kim-Phuong L. Vu

A feature-integration account of sequential effects in the Simon task

Received: 27 July 2000 / Accepted: 14 February 2003 / Published online: 6 May 2003

Abstract Recent studies have shown that the effects of irrelevant spatial stimulus-response (S-R) correspondence (i.e., the Simon effect) occur only after trials in which the stimulus and response locations corresponded. This has been attributed to the gating of irrelevant information or the suppression of an automatic S-R route after experiencing a noncorresponding trial—a challenge to the widespread assumption of direct, intentionally unmediated links between spatial stimulus and response codes. However, trial sequences in a Simon task are likely to produce effects of stimulus- and response-feature integration that may mimic the sequential dependencies of Simon effects. Four experiments confirmed that Simon effects are eliminated if the preceding trial involved a noncorresponding S-R pair. However, this was true even when the preceding response did not depend on the preceding stimulus or if the preceding trial required no response at all. These findings rule out gating/suppression accounts that attribute sequential dependencies to response selection difficulties. Moreover, they are consistent with a feature-integration approach and demonstrate that accounting for the sequential dependencies of Simon effects does not require the assumption of information gating or response suppression.

B. Hommel (✉)
Cognitive Psychology Unit, Leiden University,
Postbus 9555, 2300 RB Leiden,
The Netherlands
E-mail: hommel@fsw.leidenuniv.nl

B. Hommel
Max Planck Institute for Psychological Research,
Munich, Germany

R. W. Proctor · K.-P. L. Vu
Purdue University, W. Lafayette, Indiana, USA

A feature-integration account of sequential effects in the Simon task

Humans are highly selective about the stimuli to which they react. Before stimulus information is passed on to action control and then translated into overt behavior, a number of stimulus- and response-selection procedures are applied. These procedures make sure that the ensuing action will be a reasonable and adaptive compromise between environmental requirements and the actor's own goals and intentions. A promising research strategy to learn more about these action-shaping procedures is to examine conditions and situations in which they fail to some degree.

A well-known example for a partial failure of stimulus-response (S-R) translation and action control is the Simon effect (for overviews see Lu & Proctor, 1995; Simon, 1990). The Simon effect occurs if spatially defined responses, such as left-right key presses, are made to a nonspatial attribute (e.g., form) of a spatially varying stimulus. Although stimulus location is obviously irrelevant in such a task, spatial S-R correspondence consistently produces better performance than noncorrespondence: left responses are faster and more accurate if the stimulus also appears on the left rather than on the right, and the opposite is true for right responses.

The accepted view of the Simon effect is sketched in Fig. 1. Let us assume that people respond to the letters O and X by pressing a left and right key, respectively. If the O appears on the left, response-corresponding side, this stimulus will be processed along two routes. One route is under intentional control, and it is this route that actually realizes the task instruction. It takes the letter or stimulus form as a parameter, looks up some kind of S-R translation rule, and then activates the correct (left) response. The other route is assumed to be automatic (Hommel, 1993; Kornblum, Hasbroucq, & Osman, 1990) and unconditional (De Jong, Liang, & Lauber, 1994), and it connects the internal codes of

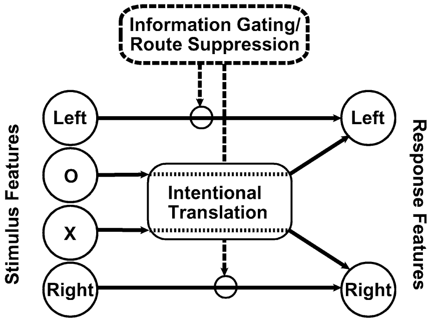

Fig. 1 Basic structure of dual-route models of S-R compatibility and the assumed influence of information gating and route suppression on automatic S-R translation. Intentional processes are represented by *broken lines*, automatic processes by *straight lines*

spatially corresponding (or otherwise similar) stimuli and responses. Along this route, the O appearing on the left will directly activate the left response. Accordingly, the left response code will receive activation via two routes and thus reach the required response threshold earlier than in a (spatially) neutral condition. However, if the O appears on the right, the intentional route activates the left response code, but the automatic route the right one, which leads to a response conflict that delays response execution.

Information gating and route suppression

The Simon effect is robust and occurs even though participants in Simon tasks are customarily instructed to ignore stimulus location. Apparently, people cannot avoid the activation of spatially corresponding responses, which seems to be a clear indication of the limitations on human control over response activation. However, Mordkoff (1998) and Stürmer, Leuthold, Soetens, Schröter, and Sommer (2002; also reported by Stürmer, Leuthold, & Sommer, 1998) analyzed the Simon effect as a function of the spatial S-R correspondence for the preceding trial. They found a sizeable Simon effect following corresponding trials but hardly any (positive) effect following noncorresponding trials. Similar results have been reported by Praamstra, Kleine, and Schnitzler (1999) and Valle-Inclán, Hackley, and de Labra (2002). This evidence that the Simon effect disappears following noncorresponding trials suggests that even "automatic" response activation may be under the control of the perceiver/actor. For example, Stürmer et al. concluded, "It appears that there is control over both routes of information processing in the Simon task" (p. 1352).

Mordkoff (1998) and Stürmer et al. (2002) proposed very similar explanations of this sequential dependency of the Simon effect, which can be traced back to De Jong (1995) and Stoffels (1996). Mordkoff refers to an "information-gating" function that can be continuously modified and adapted to increase or decrease the flow of activation from stimulus to response codes (see Fig. 1). For a corresponding trial, the response activation through the stimulus is useful (i.e., the correct response is activated via both routes), so that the activation flow is increased. If the next trial is also corresponding, this results in an increased benefit of S-R correspondence, hence in faster responding. If, however, the next trial is noncorresponding (i.e., the "opened channel" provides the wrong information), the cost of S-R noncorrespondence is also increased. Therefore, the Simon effect—i.e., the difference in performance between corresponding and noncorresponding trials—will be relatively large after a trial with S-R correspondence. In contrast, the "automatic" response activation is not useful in a noncorresponding trial (i.e., the incorrect response is activated by the spatially mediated route), so the activation flow is decreased or even blocked completely. Consequently, following a noncorresponding trial, little or no spatial information passes from stimulus to response stages, so that the impact of spatial S-R correspondence vanishes and there is no Simon effect.

Stürmer et al. (2002) similarly proposed that "control may be exerted by suppressing the unconditional route after noncorresponding events" (p. 1532), and concluded that both psychophysiological and behavioral data corroborated this view. Because the "automatic" route is suppressed after noncorresponding but not corresponding trials, irrelevant spatial information matters after corresponding trials only, so that effects depending on this information, such as the Simon effect, will only show up under these circumstances. The major difference between Mordkoff's (1998) information-gating account and Stürmer et al.'s suppression account is that gating allows the possibility that the noncorresponding response may be favored, producing a reverse Simon effect, whereas suppression does not allow for such a reversal. In the remainder of the paper, we will treat them jointly as the gating/suppression hypothesis, except when considering this one distinction.

In a sense, the idea of information-gating or route suppression provides a challenge for most models of the Simon effect and similar S-R compatibility phenomena. As already pointed out, those models essentially assume an automatic S-R route that is not under (direct and immediate) intentional control. To the extent that information gating or route suppression reflects direct control of the automatic response-selection route, in accordance with the perceiver/actor's task intentions, it would be unjustified to call this route "automatic". This point has been noted by Notebaert, Soetens, and Melis (2001), who stated, "The assumption of a blocking mechanism on the automatic response-priming route raises questions about whether the priming route really is automatic, and therefore questions one of the key features of the dual-route explanation" (p. 172).

However, the finding that the magnitude of the Simon effect varies as a function of the correspondence relation of the previous trial does not necessarily indicate that the unconditional, or automatic, route is under voluntary control, as Mordkoff (1998) and Stürmer et al. (2002) proposed. A more "automatic" interpretation of the gating/suppression hypothesis, which views gating/suppression as an automatic consequence of the activation of conflicting response codes, is possible. This interpretation will be elaborated on in the General Discussion. The main point for now is that even if a gating or suppression explanation turns out to be correct, this process may not be under the subject's control.

Integration of stimulus and response features

There is an alternative approach to the findings of Mordkoff (1998) and Stürmer et al. (2002) that attributes them to automatic consequences of the sequence of specific stimulus-response features (Notebaert et al., 2001). This explanation can be derived from the idea of stimulus- and response-feature integration proposed elsewhere (Hommel, 1998a; Hommel, Müsseler, Aschersleben, and Prinz, 2001; Stoet & Hommel, 1999). In the study of Hommel (1998a), participants performed tasks requiring, in each trial, two responses (R1 and R2) to two stimuli (S1 and S2). The first stimulus was preceded by a response cue that signaled the identity of R1 (e.g., a left vs. right key press). R1 was then prepared but not performed until S1 was presented. S1 varied randomly in form, color, and location (e.g., X vs. O, green vs. red, top vs. bottom), so that R1 did not depend on, or covary with, any of these features. About 1 s later S2 appeared, which varied on the same dimensions as S1, with one feature (form, say) signaling R2. Thus, an already prepared, simple R1 was made to the mere onset of S1, and a binary forced-choice R2 was given to the relevant feature of S2.

One might expect several kinds of repetition effects with a task like this, such as better performance for stimulus-feature repetition or a response-alternation benefit (i.e., faster response alternations than repetitions). Indeed, repetition effects were obtained, although not very reliably and only in task versions with very short intervals between S1 and S2 (Hommel & Colzato, 2003). More interesting, however, was the observation that stimulus- and response-related repetition effects interacted in a consistent fashion. In particular, there was evidence for three types of interaction. First, if stimulus form was relevant for R2, form repetitions (e.g., S1 and S2 having the same shape) produced better performance than form alternation only if the response was also repeated; if the response was alternated, form alternation yielded better performance than repetition. In other words, form-repetition benefits were obtained with response repetition but form-repetition costs with response alternation. Second, and analogously, benefits of stimulus-location repetition were obtained with response repetition, whereas location-repetition costs occurred with response alternation. Third, there were also analogous interactions between stimulus-feature repetition effects, with the most interesting one for present purposes being that between form and location: repeating stimulus form was beneficial only if location was repeated too; otherwise form repetition was associated with a cost.

A possible interpretation of these kinds of interactions is in terms of (stimulus and response) feature integration (Hommel, 1998a; Hommel et al., 2001). The basic idea is that, if a stimulus and the response to it co-occur in time, their features (at least those subsets of features related to task-relevant stimulus or response dimensions) are spontaneously integrated into a common transient representational structure or "event file". This line of thought is related to Kahneman, Treisman, and Gibbs' (1992) claim that visual object representations are based on temporary structures that contain, or refer to, feature codes belonging to a given object ("object files")—only that the term event file refers to a more general concept comprising both stimulus- and response-related feature information.

Figure 2 shows how the event-file idea can be applied to the findings of Hommel (1998a). The example refers to two succeeding trials (or parts of trials, as in Hommel's, 1998a, experiments), with the second one pairing stimulus feature S_A (e.g., letter shape *O*) and response feature R_A (e.g., location *left*; see right column). Assume that, whatever the combination of stimulus and response features (e.g., letter shapes and key press locations) in the preceding trial (see left column), these features were integrated and are now (still) associated with each other, so that reactivating one member of this temporary association tends to activate the other member. Consider what that means for processing the next S-R pair. If the same combination of stimulus and response features (O → left, O → left) were repeated, this would mean a complete match of old and new S-R features (see first row). This should not provide any particular coding or selection problem—if anything, processing might be easier than in a control condition. Similarly, no particular problems are expected for a complete mismatch of S-R features (see fourth row), for example, when the pair O → left is preceded by X → right, because the complete mismatch signals the alternative response. However, matters are more difficult with the remaining two examples, the partial matches. For instance, assume the response feature is repeated while the stimulus feature alternates (see second row) as when, the pair O → left is preceded by X → left. If, in the first trial, the letter X becomes associated with the left response, reactivating the left response in the next trial should also reactivate the associated letter X (symbolized by S_B in Fig. 2). This results in a letter-coding problem and, presumably, in response conflict as well (given that the instruction for the second trial links X to the right response). A similar problem arises if the stimulus feature is repeated while the response feature alternates (see third row), as when the pair O → left is preceded by O → right. Because the letter O has just been integrated with the right response, reactivating the letter code O will reactivate the associated right response (symbolized

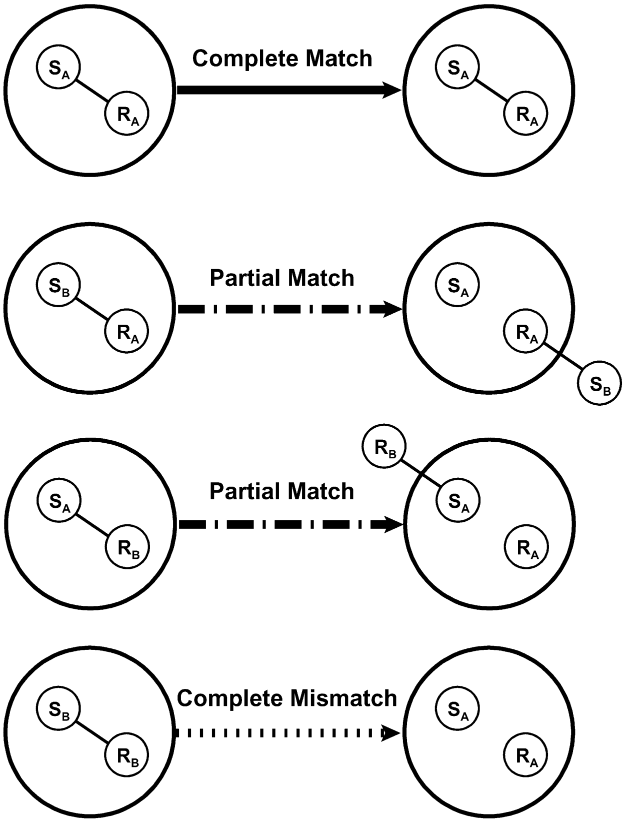

Fig. 2 The four possible combinations resulting from the repetition or alternation of binary stimulus and response features. In the example, the second part of the trial (*right column*) requires response R_A to stimulus S_A, following a stimulus-response pair with the same or different features (shown in *left column*). The critical assumption is that the codes of preceding stimulus (features) and response (features) are bound so that activating one code tends to activate the code it is integrated with. Note that (only) if there is a partial match does this lead to activation of wrong and misleading stimulus or response features

by R_B), which then competes with the correct, left response.

Although the example is given in terms of stimulus shape and response location, it applies analogously to any combination of stimulus features, response features, and mixtures between stimulus and response features, such as stimulus location and response location or stimulus form and stimulus location in the study of Hommel (1998a; see also, Proctor & Vu, 2002; Vu & Proctor, 2002). More important for present purposes is that it can also be applied to Simon tasks. Table 1 lists the four possible combinations of stimulus and response locations in a standard Simon task, as a function of the (2×2) possible locations of the preceding stimulus-response pair (see columns Preceding Pair and Present Pair). The table also indicates the ensuing correspondence relations, separately for S1-R1 pairs (the pair preceding the present pair) and S2-R2 pairs (the present S-R pair). Next, the table shows whether the succession of two given S-R pairs implies a repetition (+) or alternation (no mark) of the relevant stimulus feature (and, completely confounded with that, response location) and stimulus location (columns S/R location and S location respectively). From an event-file perspective, however, the mere repetition or alternation of a single stimulus or response feature is less crucial than the combination of feature repetitions. Good performance would be expected if two given features are either both repeated (complete match) or both alternated (complete mismatch), but interference should be obtained if one feature is repeated while the other is alternated (partial matches). Therefore, the Complete Match/Mismatch column indicates those conditions under which the relevant stimulus feature (or the response) and the irrelevant stimulus location are both repeated or both changed. In other words, this column indicates all those conditions under which the problematic partial matches do *not* occur.

The present study started from the fact that the correspondence relationship between two succeeding S-R pairs—the factor on which the gating/suppression notion hinges—is completely confounded with the presence of complete and partial matches/mismatches (see also, Notebaert et al., 2001). First, consider the trials following corresponding pairs (i.e., the rows marked in the S1-R1 Correspondence column). The corresponding conditions of this subset (i.e., the rows also marked in the S2-R2 Correspondence column) are all associated with a complete feature match or mismatch, whereas the noncorresponding conditions of this subset (i.e., the rows not also marked in the S2-R2 Correspondence column) are associated with partial matches. Assuming that complete matches and mismatches facilitate performance, this means that the reaction times (RTs) in the S2-R2 corresponding conditions are underestimated whereas those in the S2-R2 noncorresponding conditions are overestimated. In other words, the Simon effect is likely to be artificially inflated through presumably unrelated S-R integration processes.

Second, consider the trials following noncorresponding pairs (i.e., the rows not marked in the S1-R1 Correspondence column). The corresponding conditions of this subset (i.e., the rows marked in the S2-R2 Correspondence column) are not associated with a complete match/mismatch, whereas the noncorresponding conditions of this subset (i.e., the rows not marked in the S2-R2 Correspondence column) are. The RTs in the S2-R2 corresponding conditions are thus overestimated, whereas those in the S2-R2 noncorresponding conditions are underestimated. In other words, the Simon effect is likely to be artificially reduced through S-R integration processes.

Note that, according to the feature-integration account, the Simon effect is independent from the integration processes that produce the sequential effects. Consequently, the variables of S-R correspondence and complete versus partial match/mismatch should have approximately additive effects on RT.

Table 1 Mean reaction times (*RT*) and percentages of error (*PE*) for R2 in experiments 1–4, as a function of stimulus 2 (*S2*) and response 2 (*R2*) location, and stimulus 1 (*S1*) and response 1 (*R1*) location. *L* left, *R* right

Preceding pair		Present pair		Correspondence		Repetition		Complete match/ mismatch	Experiment 1		Experiment 2		Experiment 3	Experiment 4	
S1	R1	S2	R2	S1-R1	S2-R2	S/R location	S location		RT	PE	RT	PE	RT	RT	PE
L	L	L	L	+	+	+	+	+	364	0.0	418	0.0	549	458	1.3
L	L	R	L	+		+			429	2.6	510	7.3	534	527	2.5
R	L	L	L		+	+			401	0.7	464	4.8	572	466	0.0
R	L	R	L			+	+	+	375	0.0	471	1.3	572	491	1.3
L	R	L	L		+		+		444	2.1	484	1.3	580	495	5.0
L	R	R	L					+	389	0.0	474	2.5	560	498	0.0
R	R	L	L	+	+			+	370	0.0	472	0.0	543	509	0.0
R	R	R	L	+			+		433	2.1	484	3.3	580	520	1.3
R	R	R	R	+	+	+	+	+	365	0.0	409	0.0	512	423	1.3
R	R	L	R	+		+			422	4.5	549	5.4	564	506	10.4
L	R	R	R		+	+			391	1.4	450	0.0	536	482	2.5
L	R	L	R			+	+	+	373	0.0	453	3.8	540	464	2.5
R	L	R	R		+		+		411	4.0	460	1.3	577	479	3.3
R	L	L	R					+	383	0.0	450	1.3	537	477	1.3
L	L	R	R	+	+			+	350	0.0	423	0.0	514	447	0.0
L	L	L	R	+			+		437	7.1	466	2.5	556	510	1.3

Spatial correspondence between S1 and R1 and between S2 and R2 is indicated by a plus sign

Repetition of the relevant stimulus feature (confounded with response location: *S*/*R location*) and of stimulus location (*S location*) is also indicated by a plus sign

Complete repetitions or alternations of both stimulus features are marked with "+" signs in the complete match/mismatch column

No error data are available from experiment 3

Purpose of present study

The event-file perspective provides an alternative interpretation of the modulation of the Simon effect by the trial sequence without assuming information gating, route suppression, or other processes controlling "automatic" pathways. This interpretation is attractive because it does not require major changes to current models of the Simon effect. Also, it would fit nicely with the findings of Hommel (1998a). However, the confounding of the two critical factors (correspondence relationship and complete-partial match/mismatch) in the previous experiments is not simply an avoidable methodological flaw but a basic characteristic of the Simon task due to its restriction to two-choice tasks. Consequently, it is difficult to devise an experimental manipulation within the context of the Simon task that can provide a clear-cut empirical decision between the gating/suppression hypothesis and an integration account. As a result, the present study did not so much aim at ruling out one or the other alternative but, rather, at demonstrating that an event-file approach may suffice to account for sequential dependencies, and how it can do so. Moreover, it will be shown that this approach suggests novel and interesting predictions that are confirmed by the empirical findings. These findings also exclude some (though not all) types of route-suppression models, specifically, those that attribute the suppression to control processes that solve response-selection difficulties, thereby putting tight constraints on further theorizing.

The rationale underlying the present study was as follows. First, we tested whether comparable effects can be obtained in a Simon-type task (experiment 1) and a prime-probe type of task like that used in Hommel's (1998a) study (experiment 2). If similar results can in fact be obtained, and if these results were comparable to those in event-file studies (e.g., Hommel, 1998a), this would justify attempting to account for them in a comparable way, hence, in terms of S-R feature integration. Second, the role of actual response selection for sequential effects was investigated by manipulating the task conditions in a way that made stimulus-induced problems in response selection unlikely. In experiment 3, each critical S-R corresponding or noncorresponding trial was preceded by a trial that required no response, that is, S2 and R2 were preceded by S1 but not R1. In experiment 4, R1 was triggered by a tone while S1 appeared much later, so that most of the time S1 followed rather than preceded R1. If under these conditions correspondence effects were still dependent on the (actual or implied) S-R correspondence in the preceding trial, this would rule out those versions of a gating/suppression approach that attribute sequential effects to response-selection difficulties or their solution.

Experiment 1

Experiment 1 aimed at replicating the finding that the Simon effect depends on whether or not the stimulus and response locations corresponded on the preceding trial (e.g., Mordkoff, 1998; Stürmer et al., 2002). Because experiments 2–4 used the Hommel's (1998a) design, which consists of two S-R pairs in each trial, the same design was also employed in experiment 1. A standard Simon task was administered, with left-right responses to letter shapes that varied randomly in their horizontal location. Groups of two S-R pairs were created, somewhat arbitrarily, by increasing the intertrial intervals after every second S-R pair. The first S-R pair of each of these groups was treated as prime or "preceding trial" (S1-R1), and the second pair as probe or "present trial" (S2-R2).

Two types of computations were performed on the same data set. One analyzed the Simon effect as a function of correspondence in the preceding trial, that is, the dependence of S2-R2 correspondence on S1-R1 correspondence. Following the previous studies, one would expect S2-R2 Simon effects to be present with S1-R1 correspondence, but absent, or at least substantially reduced, with S1-R1 noncorrespondence. A second analysis followed the logic of the integration approach suggested by Hommel (1998a). Accordingly, the data were analyzed as a function of the repetition versus alternation of stimulus form (here confounded with response location) and stimulus location. The integration approach predicts that form/response and location are integrated, so that the two repetition effects were expected to interact. In particular, better performance was expected when stimulus form (and response) and stimulus location were both repeated or both alternated (i.e., complete matches or mismatches of features) as compared with conditions when one was repeated and the other alternated (i.e., partial matches). Moreover, given the confounding of stimulus form and response location and, thus, the possible combination of form-location and response-location integration effects (which Hommel, 1998a, showed to make independent contributions), the interaction effect should be rather pronounced in comparison with experiment 2, where independent estimates of form-location and response-location integration effects could be obtained.

At this point, it is important to bear in mind that the analyses of the Simon effect as a function of preceding trial correspondence and of stimulus and response repetition are alternative computations on the same data set. Therefore, correctly predicting the outcome of their respective analysis is a minimal requirement for each account but not necessarily an indication of the superiority of one over the other.

Method

Participants

Sixteen adults (9 female and 7 male, aged 21–38 years) were paid to participate in single sessions of about 30 min. They reported having normal or corrected-to-normal vision and were not aware of the purpose of the experiment.

Apparatus and stimuli

The experiment was controlled by a Hewlett Packard Vectra QS20 computer, attached to an Eizo 9080i monitor. All stimuli were taken from the EGA system letter font and were presented on a black background. From a viewing distance of about 60 cm, participants faced three gray adjacent boxes, horizontally arranged square outlines of about 1.2°×1.2°. An asterisk served as fixation mark, which appeared in white at the center of the middle box. The letters O and X were used as stimuli, which appeared in green, randomly at the center of the left or right box (i.e., 1.2° left or right of fixation). Responses were made by pressing the left or right of two board-mounted microswitches with the index finger of the left and right hand respectively.

Procedure and design

Half of the participants responded to the O and X by pressing the left and right response key respectively, whereas the other half received the opposite mapping. In each trial, two stimuli (S1 and S2) were presented and two responses (R1 and R2) were given. After an intertrial interval of 2,000 ms, the fixation mark appeared for 1,500 ms, followed by a blank interval of 1,000 ms. Then S1 appeared for 400 ms to signal R1. If R1 was performed with the wrong key, faster than 10 ms (i.e., if it was truly anticipatory), or slower than 800 ms, it was considered incorrect, premature, or omitted respectively, and the trial ended immediately with a short visual error feedback. Otherwise, S2 signaled R2 1,000 ms after the onset of S1 (i.e., 200 ms after maximum RT). S2 remained visible for up to 2,000 ms until R2 was given. If R2 was performed with the wrong key, faster than 10 ms, or slower than 2,000 ms, it was considered incorrect, premature, or omitted, respectively. In any of these cases, a short visual error feedback was presented, while the trial was recorded and repeated at some random position in the remainder of the block.

There were four within-group variables, location of S1 (left vs. right), location of R1 (left vs. right, correlated with S1 form), location of S2 (left vs. right), and location of R2 (left vs. right, correlated with S2 form). Each participant worked through one practice block and eight experimental blocks, with the opportunity for a break after completing the first two, four, and six experimental blocks. Each block was composed of 16 randomly intermixed trials, resulting from the factorial combination of the four binary variables.

Results

R1, the first response in each trial, was never given prematurely and was omitted in 1.3% of the trials. From the remaining data, mean RTs and percentages of error (PEs) were computed as a function of S1-R1 correspondence (S1 left and R1 left or S1 right and R1 right) or noncorrespondence (S1 left and R1 right or S1 right and R1 left). The significance criterion was set to $p < .05$ for all analyses. R1 was performed faster, $F(1, 15) = 23.15$, $MSE = 225.38$, and tended to be more accurate ($p < .1$) with S1-R1 correspondence (436 ms and 1.3%) than noncorrespondence (461 ms and 2.9%). Thus, there was a reliable Simon effect of 25 ms in the RTs and a corresponding pattern in the error rates.

R2, the second response in each trial, was always made prior to the deadline. The RTs and PEs are listed in Table 1. These data, which were of most interest, were aggregated and analyzed in two ways.

First, mean RTs and PEs were computed as a function of S2-R2 correspondence (S2 left and R2 left or S2 right and R2 right) or noncorrespondence (S2 left and R2 right or S2 right and R2 left) and S1-R1 correspondence (S1 left and R1 left or S1 right and R1 right) or noncorrespondence (S1 left and R1 right or S1 right and R1 left). The Correspondence columns in Table 1 show the coding scheme used. The means computed in this manner were submitted to 2 (correspondence of present S-R pair) × 2 (correspondence of preceding S-R pair) ANOVAs, similar to the analyses performed by Stürmer et al. (2002) and Mordkoff (1998). We will refer to these analyses as *correspondence effects* analyses.

Second, mean RTs and PEs were computed as a function of repetition vs. alternation of stimulus form or response location (both being perfectly confounded in experiment 1) and repetition vs. alternation of stimulus location. The Repetition columns in Table 1 show the coding scheme used. The means computed in this way underwent 2 (repetition of stimulus form/response location) × 2 (repetition of stimulus location) ANOVAs, corresponding to the analyses performed by Hommel (1998a). We will refer to these analyses as *repetition effects* analyses.

Correspondence effects

Two effects were significant in the RT data: the main effect of S2-R2 correspondence, $F(1, 15) = 14.89$, $MSE = 356.91$, and the interaction of S1-R1 correspondence and S2-R2 correspondence, $F(1, 15) = 117.65$, $MSE = 338.34$. Figure 3 (upper left panel) shows that the correspondence of S2 and R2 had a pronounced positive effect if the preceding trial or S-R pair (i.e., S1 and R1) was corresponding (362 vs. 430 ms), but a negative effect if it was noncorresponding (412 vs. 380 ms). In the PEs, only the interaction was significant, $F(1, 15) = 13.19$, $MSE = 11.39$, indicating that the effect of S2-R2 correspondence was positive following a corresponding pair (0.0% vs. 4.1%) but negative after a noncorresponding pair (2.0% vs. 0.0%).

Repetition effects

In the RTs, the main repetition effects were small (see Fig. 4, top panel) and unreliable, but the interaction of stimulus form/response location and stimulus location was significant, $F(1, 15) = 117.65$, $MSE = 338.34$. RTs were fast if form and location were both repeated (369 ms) or both alternated (373 ms), but slow if only form (411 ms) or only location (431 ms) was repeated while the other feature was alternated. Thus, performance of R2 was slowed by 50 ms if feature repetition and alternation were mixed. Hommel (1998a) referred to such an effect pattern as a *feature-conjunction benefit*, which is represented in a condensed form in Fig. 4 (bottom panel). In the PE analysis, all three effects were significant: location repetition, $F(1, 15) = 6.15$, $MSE = 1.52$, form (and response) repetition, $F(1, 15) = 6.15$, $MSE = 1.52$, and the interaction, $F(1, 15) = 13.19$, $MSE = 11.39$. Analogous to the RTs, errors were restricted to conditions in which only either form (2.3%) or location (3.8%) was repeated, but did not occur when both form and location were repeated or alternated.

Discussion

The results are in good agreement with the key observation of Mordkoff (1998) and Stürmer et al. (2002) that Simon effects occur after performing corresponding but not noncorresponding trials. Interestingly, the Simon effect was not only eliminated after noncorresponding trials but was inverted for both RTs and errors. An inversion is not predicted by the suppression hypothesis alone because it assumes that the S-R associations are shut down after noncorresponding trials. Although it is obvious that cutting off the flow of spatial information

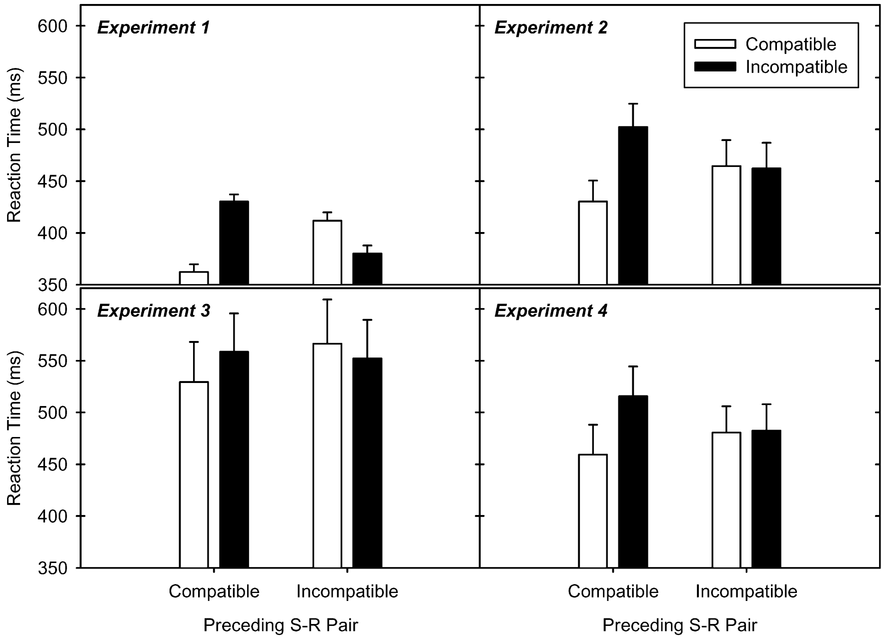

Fig 3 Reaction times for R2 in experiments 1–4, as a function of S2-R2 compatibility and S1-R1 compatibility. *Error bars* represent standard errors

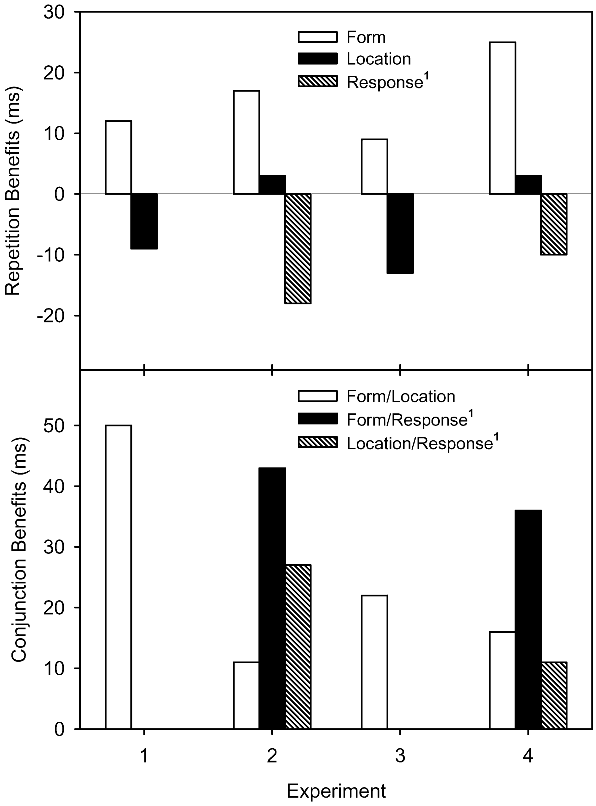

Fig. 4 Repetition benefits ($RT_{alternation}$-$RT_{repetition}$) and conjunction benefits ($RT_{partial\ repetition}$-$RT_{complete\ repetition\ or\ alternation}$) for stimulus form and location, and response location in experiments 1–4. ¹In experiments 1 and 3 response location was confounded with stimulus form

from stimulus to response might prevent any impact of spatial correspondence on response selection, it is hard to see how this could reverse a Simon effect. The pattern of results is more consistent with the gating hypothesis because it allows differential weighting of S-R associations after corresponding and noncorresponding trials, and these weightings could be made to favor the noncorresponding response.

The results of the alternative repetition-effect analyses were also in keeping with previous findings. The absence of the main effects of stimulus features and the presence of an interaction between stimulus form and stimulus location replicate the findings of Hommel (1998a). This is important to know because Hommel used spatially orthogonal stimulus and response sets (top-bottom stimuli and left-right responses), whereas the present stimuli and responses varied on the same spatial dimension. Apparently, the integration effect survived this modification, which confirms that the event-file idea can actually be applied to Simon-type tasks with their feature-overlapping stimulus and response sets. Moreover, the interaction effect is rather pronounced, suggesting that it combines contributions from form-response integration and location-response integration. We will come back to this issue in experiment 2.

The outcome of the two types of analyses only shows that two different interpretations are tenable but not that one is superior. An interpretation in terms of S-R integration is more powerful, as it accounts for both the present findings and those of Hommel (1998a), whereas the gating/suppression hypothesis only applies to the dependence of the Simon effect on the correspondence relation of the previous trial. That is, if the gating/suppression account is favored over an integration explanation, an explanation would need to be found as to why integration as observed in Hommel's (1998a) study did not take place here or in the experiments of Mordkoff (1998) or Stürmer et al. (2002). Nevertheless, there may still be important methodological differences between Simon-type tasks, including the present one, and the tasks used in the previous event-file studies. Experiment 2 investigated whether these differences are of relevance.

Experiment 2

The basic idea pursued in this article rests on the assumption that, from an event-file perspective, the Simon task and the prime-probe task used by Hommel (1998a) are comparable and thus produce similar results. In fact, experiment 1 demonstrated that integration-type effects can be observed in a standard Simon task. However, it still needs to be shown that the critical dependence of Simon effects on the preceding trial is also obtained in the prime-probe tasks so far employed to investigate feature integration. Experiment 2 tested whether this can be done. As in the Hommel's (1998a) study, two S-R pairs were presented in each trial, the first being the prime and the second the probe. In contrast to the Simon-type version used in experiment 1, R1 was always signaled in advance, so that S1 only triggered an already prepared response. Moreover, the features of S1 varied randomly, so that there was no correlation between R1 and any one S1 feature.

From an event-file perspective, these procedural changes should affect the outcome quantitatively but not qualitatively. On the one hand, the design of experiment 2 unconfounds stimulus form and response effects, thus allowing the effects of form-(stimulus-)location integration to be separated from those of response-(stimulus-)location integration. Therefore, a smaller form-location effect was expected than in experiment 1, in which form and response were confounded. Moreover, as S1 now merely functioned as a trigger, a more superficial stimulus analysis may be expected and, hence, a smaller degree of feature integration. On the other hand, except for using spatially parallel stimulus and response sets, the design of experiment 2 was very similar to that used by Hommel (1998a), where integration effects occurred in the first place, so that some degree of S1-R1 integration should clearly be demonstrated.

From a gating/suppression view, predictions depend on whether R1 selection is associated with a stimulus-induced response conflict. Logically, the present task allows the completion of R1 selection long before S1 appears. If R1 were actually selected early, S1 would be coded far too late to affect R1 selection, so that S1-R1 Simon effects would be absent. Accordingly, S2-R2 Simon effects should not depend on S1-R1 correspondence. However, effects of spatial S-R correspondence have been observed even with full knowledge of the upcoming response. For instance, Hommel (1995, 1996) signaled a left-right response previously to a lateralized go stimulus, with the result that spatial correspondence between go stimulus and already prepared response facilitated performance. This suggests that response selection cannot be fully completed before actual execution, so that prepared responses cannot be shielded from stimulus-induced response conflict. If so, the gating/suppression hypothesis predicts that S2-R2 compatibility effects depend on S1-R1 correspondence, even with the present task version. Fortunately, this version provides a direct measure of the degree of response conflict S1-R1 performance through the effect of S1-R1 correspondence on speed and accuracy of R1. This allows for an independent test of the preconditions for the predictions from the gating/suppression hypothesis.

Method

Sixteen adults (11 female and 5 male, aged 18–38 years) fulfilling the same criteria as in experiment 1 participated for pay. The method was as in experiment 1, with the following exceptions. There was no fixation mark, but a response cue consisting of a row of three white left- or right-pointing arrows was presented at the center of the middle box. Each trial comprised three visual stimuli (response cue, S1, and S2) and two responses (R1 and R2). The response cue, which signaled R1, appeared for 1,500 ms at the beginning of the trial, followed by a 1,000-ms blank interval. Then S1 was presented, which triggered R1. Thus, the identity of S1 was completely irrelevant for R1, which was specified by the response cue, and the correlation of S1 and R1 was zero. If R1 was performed with the wrong key, faster than 10 ms, or slower than 600 ms, it was considered incorrect (premature, or omitted respectively), and the trial ended immediately with a short visual error feedback. Otherwise, S2 signaled R2 1,000 ms after the onset of S1 (i.e., 400 ms after maximum RT), and the trial proceeded as in experiment 1.

There were five within-group variables, form of S1 (O vs. X), location of S1 (left vs. right), location of R1 (left vs. right), location of S2 (left vs. right), and location of R2 (left vs. right, correlated with S2 form). Each participant worked through one practice block and four experimental blocks, with the opportunity for a break after completion of the first, second, and third experimental block. Each block was composed of 32 randomly intermixed trials, resulting from the factorial combination of the five binary variables.

Results

R1 was prematurely initiated in 0.3% and omitted in 4.4% of the trials. In the remaining trials, mean RT was 318 ms and the PE was 0.8%. R2 responses were never prematurely initiated and omitted in less than 0.1% of the trials. The following analyses are based on the remaining data.

Correspondence effects

To allow for a meaningful comparison between experiments 1 and 2, only those conditions were analyzed in which the coupling of S1 form and R1 followed the mapping of R2 on S2, so that, again, S1 form and R1 location were confounded (see Table 1). From these data, mean RTs and PEs for R2 were computed as a function of S1-R1 correspondence and S2-R2 correspondence.

In the RTs the main effect of S2-R2 correspondence was significant, $F(1, 15) = 20.85$, $MSE = 934.21$, as was the interaction with S1-R1 correspondence, $F(1, 15) = 32.34$, $MSE = 682.45$. Figure 3 (upper right panel) shows that the correspondence of S2 and R2 again had a pronounced positive effect if S1 and R1 were corresponding (431 vs. 465 ms), but no effect if S1 and R1 were noncorresponding (465 vs. 462 ms). The PEs also produced a main effect of S2-R2 correspondence, $F(1, 15) = 4.63$, $MSE = 21.58$, and an interaction, $F(1, 15) = 7.61$, $MSE = 9.52$, the latter showing that S2-R2 correspondence had a positive effect after corresponding (0.0% vs. 4.6%) but not noncorresponding (1.8% vs. 2.2%) S1-R1 pairs.

We also tested whether performance on R1 was affected by S1-R1 correspondence. In fact, R1 was significantly faster, $F(1, 15) = 20.04$, $MSE = 379.29$, and tended to be more accurate ($p < .07$) with S1-R1 correspondence (301 ms and 0.0%) than noncorrespondence (332 ms and 1.1%).

Repetition effects

All conditions were considered and analyzed as a function of stimulus form repetition, stimulus location repetition, and response repetition. In the RTs, main effects were obtained for form repetition, $F(1, 15) = 12.47$, $MSE = 722.79$, and response repetition, $F(1, 15) = 10.55$, $MSE = 992.27$, indicating repetition benefits for form and alternation benefits for responses (see Fig. 4, upper panel). Stimulus-form and response repetition also interacted, $F(1, 15) = 18.07$, $MSE = 3{,}302.02$, as did stimulus-location and response repetition, $F(1, 15) = 25.50$, $MSE = 884.43$. The pattern of these effects was similar to that in experiment 1. Response times were fast if stimulus form and response were both repeated (466 ms) or both alternated (464 ms), but slow if only form (491 ms) or only the response (525 ms) was repeated. Likewise, responses were faster if stimulus location and response were both repeated (481 ms) or both alternated (466 ms), but slow if only location (489 ms) or only the response (510 ms) was repeated. Figure 4 (lower panel) gives a condensed overview of these effects. Finally, the three-way interaction was significant, $F(1, 15) = 7.33$, $MSE = 1{,}045.34$, the complex pattern of which is shown in Fig. 5. Interestingly, however this pattern is read, the interaction of two given factors is always stronger if the third factor is "repeated" rather than "alternated", which may be taken to point

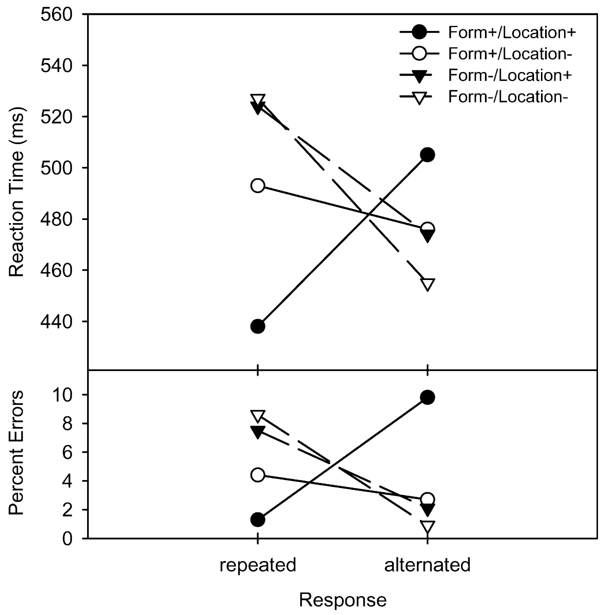

Fig. 5 Reaction times in experiment 2 as a function of response repetition vs. alternation, stimulus form repetition (*Form+*) vs. alternation (*Form−*), and stimulus location repetition (*Location+*) vs. alternation (*Location−*)

to a complete integration of both stimulus features and the response.

The error analysis revealed a similar pattern as the RTs. Two-way interactions were obtained for repetition of stimulus form and response, *F*(1, 15) = 37.39, *MSE* = 21.41, and stimulus location and response, *F*(1, 15) = 8.71, *MSE* = 35.76. Errors were less frequent if stimulus form and response were both repeated (2.8%) or both alternated (1.5%) than if only form (6.3%) or the response (8.1%) was repeated. Likewise, fewer errors were made if stimulus location and response were both repeated (4.4%) or both alternated (1.8%) than if only location (6.0%) or the response (6.5%) was repeated. As in the RTs, the three-way interaction was significant, *F*(1, 15) = 8.98, *MSE* = 14.25, showing basically the same pattern (see Fig. 5).

Discussion

Although, in contrast to experiment 1, S1 and R1 were uncorrelated in the present experiment, the major findings were replicated. First, the effect of S2-R2 correspondence was strongly affected by the correspondence between S1 and R1. This is consistent with the integration hypothesis, inasmuch as it attributes this effect to S1-R1 binding, which again should not be affected by the causal relationship between S1 and R1. However, note that S1-R1 correspondence produced an effect of its own (i.e., on R1), indicating that S1-induced response conflict was present in R1 selection. Consequently, the outcome is also in agreement with the gating/suppression hypothesis, which assumes that the experience of S-R conflict leads to the blocking of spatial information from access to response stages.

Second, the effects of feature repetition again interacted in the expected way. Given that it was now possible to unconfound form and response repetition, the outcome pattern is necessarily more complex than in experiment 1. For example, the repetition benefit of form is slightly greater than in experiment 1 and is accompanied by a cost of response repetition. This suggests that the small, unreliable form/response benefit in experiment 1 actually represented a mixture of these two opposite effects. Likewise, the strong interaction between form/response and stimulus location observed in experiment 1 has now given way to a small, unreliable interaction of form and location, and a much more pronounced interaction of stimulus location and response. Again, this suggests that the pronounced form-location interaction in experiment 1 was mainly due to the confounding of stimulus form and response location. In fact, Hommel (1998a) consistently obtained smaller and less reliable interactions between stimulus form and stimulus location than between stimulus location and response location. Finally, the unconfounding of form- and response-related effects revealed a strong interaction between form and response repetition. That this interaction was obtained at all, and that it is the most pronounced effect, is in agreement with the Hommel's findings (1998a).

An unexpected and novel finding is the significant three-way interaction of form, location, and response repetition. Such a higher-order interaction was not observed in Hommel (1998a) or in any other unpublished work of which we are aware, and it was not replicated in experiment 4 of the present study. From a theoretical point of view, such a pattern is interesting because it suggests full integration of all event features (i.e., stimulus and response) into a single, coherent representation. However, given the uniqueness of this finding, a far-reaching interpretation would be premature at this point.

Most importantly, experiment 2 supports the crucial assumption that the basic Simon task and the prime-probe design introduced by Hommel (1998a) are comparable. In fact, experiments 1 and 2 produced very similar results. Moreover, the results of experiment 2 resemble those obtained in Hommel's study (1998a), even though the stimulus and response features did not overlap as in the present experiment. This has obvious theoretical implications. If the interactions between repetition effects observed in the two studies are comparable in type and size, it is reasonable to assume that they have the same origin. If so, an account of the outcome pattern in experiment 2 in terms of S-R integration is fully sufficient. Thus, there is no need for a gating/suppression account, the more so as this account is unable to explain Hommel's (1998a) findings. Given that the results of the present experiments 1 and 2 were also comparable, the same argument holds for experiment 1 as well as for the experiments by Mordkoff (1998) and Stürmer et al. (2002). Nevertheless, these findings do not rule out a gating/suppression approach either.

Experiment 3

As pointed out in the introduction, it is difficult to test between the gating/suppression account and the integration account because most of their predictions are similar. However, there are at least two different versions of the gating/suppression account. On the one hand, gating/suppression may be thought to result from the successful selection of a response. According to the common dual-route model, processing a stimulus leads to both the automatic activation of the spatially corresponding response (whether right or wrong) and the controlled activation of the correct response. In corresponding trials, only the correct response is activated, whereas in noncorresponding trials, both responses are activated. Therefore, selecting a response in a noncorresponding trial presupposes some struggle with the misleading activation from the automatic route, and it may be this struggle that eventually leads to the partial or complete blocking of information this route transmits. If so, route suppression should fully depend on response-selection problems and, hence, should not be observed if such problems do not occur. This intentional "response-selection" version of the gating/suppression approach will be critically examined in experiments 3 and 4. However, as developed in the General Discussion, it may also be possible that gating/suppression is an automatic consequence of detecting (response?) conflict as such, independent of any response-selection processes. This more "adaptive" version makes much the same predictions as the integration approach—at least under the conditions investigated in this study—and therefore could not be tested against the integration account.

According to the response-selection version of the gating/suppression approach, sequential dependencies of the Simon effect arise as a consequence of selecting a response against a competing response in the preceding trial. If so, changing the task in a way that makes response selection unnecessary should eliminate the dependence of Simon effects on the preceding trial. This implication was tested in experiments 3 and 4. Experiment 3 attempted to eliminate response selection in the "preceding" trial in the most obvious way, namely by eliminating R1. The task was as in experiment 1, only that participants no longer responded to S1. Accordingly, response selection was not required in the "prime" part of the trials, so that performance in the "probe" part was unlikely to be affected by aftereffects arising from response-selection processes. Therefore, any account focusing on response-selection processes predicts that the Simon effect for S2-R2 will not vary as a function of the correspondence between S1, the actually presented, preceding stimulus, and R1, the withheld response signaled (or implied) by S1.

Making predictions from the integration hypothesis requires some further considerations about the control of S-R translation. Logically, S1 does not need to be translated into R1 because R1 need not be carried out. However, there is independent evidence that, once a set of S-R rules is implemented to solve a task, the respective rules are applied even if this is unnecessary or unwanted. For instance, Hommel (1998b; Hommel & Eglau, 2002) presented participants with red or green letters and asked them to perform either a manual left-right response to the color of the stimulus or a verbal color-name response to the letter shape. Which response to make in a given trial was signaled in advance. Interestingly, manual responses were faster if the (not required) verbal response to the stimulus would have been a stimulus-compatible color name (e.g., red stimulus and verbal response "red"). This suggests that the "verbal" S-R rules were automatically applied even in manual trials. Comparable effects have been reported by Logan and colleagues (Logan & Gordon, 2001; Logan & Schulkind, 2000). Other evidence comes from Marble and Proctor (2000), who mixed for which stimulus location was relevant, and mapped incompatibility to responses, with Simon trials for which stimulus color was relevant and stimulus location irrelevant. In their experiment 3, the task was precued at varying intervals of up to 2,400 ms prior to presentation of the imperative stimulus. For the Simon task, a reversed Simon effect, indicating the influence of the incompatible mapping, was evident at all precuing intervals, including the longest one. Likewise, when people alternate rapidly between two tasks, they produce better performance if a given stimulus requires the same response in either task (Meiran, 1996; Rogers & Monsell, 1995).

All of these findings indicate that the currently invalid S-R rules are not switched off completely. If they are not switched off completely, one would expect that in experiment 3 presenting S1 will lead to some activation of the assigned R1, even though this is not required by the task. S1 and R1 will therefore be activated (to some degree) at the same time, so that some S-R integration (mimicking an aftereffect of S1-R1 correspondence) should occur, as in experiments 1 and 2.

Method

Sixteen adults (15 female and 1 male, aged 17–30 years) fulfilling the same criteria as in experiment 1 participated for pay. The task and procedure were as in experiment 1, except that no response was required to the first stimulus (S1). Thus, in each trial participants saw two stimuli but responded to the form of the second only. If they responded to the first stimulus, the trial ended immediately and was repeated at some random position in the remainder of the block.

Results

Due to an error in the experiment's control program, the data from incorrect trials were not recorded (but correctly excluded), so that the analyses are based on RTs for correct trials only (see Table 1).

Correspondence effects

In analogy to experiment 1, mean RTs were computed as a function of S2-R2 correspondence and implied S1-R1 correspondence, that is, as to whether the response signaled by S1 would have been spatially corresponding or noncorresponding. There was a main effect of S1-R1 correspondence, $F(1, 15) = 5.22$, $MSE = 719.27$, and a significant interaction, $F(1, 15) = 6.72$, $MSE = 1{,}124.49$. Figure 3 (bottom left panel) shows that S2-R2 correspondence had the usual positive effect if S1 and (implied) R1 were corresponding (530 vs. 559 ms), but tended to have a negative effect if S1 and R1 were noncorresponding (566 vs. 552 ms).

Repetition effects

Response times were analyzed as a function of stimulus form repetition (confounded with "implied" response repetition) and stimulus location repetition. Although the results showed the same pattern as in experiment 1 regarding both repetition and conjunction benefits (see Fig. 4), only the interaction was significant, $F(1, 15) = 6.72$, $MSE = 1{,}124.49$. As in experiment 1, responses were faster if form and location were both repeated (543 ms) or both alternated (539 ms) than if only form (552 ms) or response (573 ms) were repeated.

Discussion

The results are clear-cut. As predicted from the integration approach, there was again evidence for the integration of stimulus form and location. Even the size of this effect—comparable to those in experiments 2 and (to anticipate) 4, but much smaller than in experiment 1, where form and response were confounded—was to be expected. In contrast, the outcome is difficult to interpret from any account that focuses on R1 selection. Such an account would need to explain why the results of experiments 1 and 2 were replicated, even though in experiment 3 the "corresponding" or "noncorresponding" relationship between S1 and R1 was only implied and no R1 was to be selected.

Experiment 4

Experiment 3 attempted to prevent any difficulty with selecting R1 by not having the participants perform the response. Nevertheless, the Simon effect for S2-R2 varied as a function of correspondence between S1 and implied R1, which speaks against response selection as a critical factor in producing sequential correspondence effects. To provide converging evidence, experiment 4 aimed at the same goal as experiment 3 but used a slightly different technique. Instead of presenting S1 without R1, R1 was now to be given before S1 appeared, so that it could not be influenced by S1 (or the response activated by S1) for trivial temporal reasons. This should be critical for any response-centered hypothesis, because it should now be impossible for S1-R1 correspondence to affect performance on R1. Accordingly, there is little reason to gate spatial information, or suppress its delivery to response stages, any differently after experiencing S1-R1 corresponding than noncorresponding primes. In contrast, integration is not affected by the order of stimulus and response. For instance, Hommel (1998c) used a tone to trigger the prepared R1 and presented the visual S1 (now void of any function) up to 500 ms before or after the tone, so that S1 could precede or follow R1. However, the interactions between repetitions of stimulus and response features did not depend on the direction or length of the asynchrony between the tone and S1 (cf., Dutzi & Hommel, 2003), suggesting that stimulus and response information is integrated over a rather broad time window. If so, experiment 4 should produce integration effects of the same sort as observed in experiments 1–3, including the effects of form-location integration that look like aftereffects of S1-R1 correspondence.

Method

Sixteen adults (14 female and 2 male, aged 19–36 years) fulfilling the same criteria as in experiment 1 participated for pay. The method was as in experiment 2, with the following exceptions. Execution of the previously cued and prepared R1 was not signaled by a visual stimulus but a 50-ms sinusoidal tone of 500 Hz, simultaneously presented through two loudspeakers to the left and right of the monitor. The visual stimulus (which we still refer to as S1) appeared 400 ms after the tone onset for 200 ms[1], and it was not correlated with R1. Given the mean RT for R1 of 267 ms (see below), this meant that S1 appeared on average more than 100 ms after R1. Then, 1,400 ms after tone onset and 1,000 ms after S1 onset, S2 signaled R2 and the trial proceeded as in experiment 2. The only further change was that the criterion for premature responses was set at 60 ms.

Results

R1 was prematurely initiated in 0.5% and omitted in 3.2% of the trials. In the remaining trials, mean RT was 267 ms and the PE was 0.1%. R2 responses were prematurely initiated in 0.5% of the trials and never omitted. The following analyses are based on the remaining data.

---

[1] Using a fixed tone-S1 interval has the advantage of keeping the S1-S2 interval constant, but it introduces variability in the R1-S1 interval. The obvious alternative of presenting S1 at R1 onset has the advantage of keeping the R1-S1 interval constant, but it introduces variability in the S1-S2 interval. As the data available thus far suggest that the S1-S2 interval has a much stronger impact on S-R feature integration than the R1-S1 interval (Dutzi Hommel, 2003; Hommel Colzato, 2003), we preferred the first option.

Correspondence effects

As in experiment 2, only those conditions were analyzed in which the coupling of S1 form and R1 followed the mapping of R2 on S2, so that S1 form and R1 were confounded. Moreover, the data were again treated as if R1 would have been made to S1, so that S1-R1 "corresponding" and "noncorresponding" pairings could be identified, although this time S1 actually followed R1 (see Table 1).

In the RTs, the main effect of S2-R2 correspondence was significant, $F(1, 15) = 10.12$, $MSE = 1{,}343.41$, as was the interaction of this variable with S1-R1 correspondence, $F(1, 15) = 11.41$, $MSE = 1{,}037.23$. Figure 3 shows that the correspondence of S2 and R2 again had a pronounced positive effect if S1 and R1 were corresponding (459 vs. 516 ms), but no effect if S1 and R1 were noncorresponding (481 vs. 483 ms). In the PEs, the interaction produced a significant effect, $F(1, 15) = 14.55$, $MSE = 6.04$, due to S2-R2 correspondence having a positive effect after S1-R1 corresponding trials (0.6% vs. 3.9%) but a negative effect after noncorresponding trials (2.7% vs. 1.2%).

We also checked for the possible impact of S1 on R1. Logically speaking, it might have been that S1 location affected those responses that were slow enough to follow the onset of S1 (i.e., RT1 > 400 ms) but still fast enough to meet the RT deadline (RT1 < 600 ms), even though taking into consideration the temporal demands of S1 analysis (which must precede any impact on responses) and of R1 programming and execution (which must precede the key press) leaves only a very brief time window for such an impact to unfold. First, we tested whether RT1 would show any indication of an S1-R1 compatibility effect, but this effect was far from significant, $F(1, 15) < 1$, and numerically inverted (267 vs. 262 ms). Second, we re-ran the analysis of RT2 after excluding all trials in which RT1 was longer than 400 ms. The outcome was virtually identical to the original analysis: there was a main effect of S2-R2 correspondence, $F(1, 15) = 17.14$, $MSE = 1{,}015.50$, and an interaction with S1-R1 correspondence, $F(1, 15) = 7.21$, $MSE = 1{,}215.51$, the latter indicating that the correspondence of S2 and R2 had a substantial effect if S1 and R1 were corresponding (457 vs. 514 ms) but no effect if S1 and R1 were noncorresponding (471 vs. 480 ms).

Repetition effects

The total data set was analyzed as a function of stimulus form repetition, stimulus location repetition, and response repetition. For RTs, the main effect of form repetition was significant, $F(1, 15) = 8.69$, $MSE = 2{,}338.31$, and that of response repetition tended to be so ($p < .06$). As shown in Fig. 4 (upper panel), the pattern of these effects was as in experiment 2, with the form effect being positive and the response effect being negative. Moreover, all two-way interactions were significant: form by response, $F(1, 15) = 9.68$, $MSE = 4{,}184.82$, location by response, $F(1, 15) = 4.53$, $MSE = 923.23$, and form by location, $F(1, 15) = 11.50$, $MSE = 691.47$. Figure 4 (lower panel) shows that, again, the pattern of these effects was as in experiment 2. Response times were fast if stimulus form and response were both repeated (477 ms) or both alternated (492 ms), but slow if only form (502 ms) or response (538 ms) was repeated. Similarly, responses were somewhat faster if stimulus location and response were both repeated (500 ms) or alternated (493 ms), than if only location (502 ms) or response (514 ms) was repeated. Finally, RTs were shortest if both stimulus features were repeated (480 ms), longer if both were alternated (508 ms) or only form was repeated (499 ms), and longest if only location was repeated (521 ms).

The PE analysis revealed a similar picture to that observed in the RTs. There was a main effect of response repetition, $F(1, 15) = 6.33$, $MSE = 11.93$, indicating more errors being made with response repetition than alternation (4.1% vs. 2.5%), as well as interactions between form and response repetition, $F(1, 15) = 8.18$, $MSE = 21.90$, and between location and response repetition, $F(1, 15) = 12.74$, $MSE = 17.72$. Errors were less frequent if stimulus form and response were both repeated (2.7%) or alternated (1.5%) than if only form (3.5%) or response (5.4%) was repeated. Similarly, fewer errors were made if stimulus location and response were both repeated (2.9%) or alternated (1.0%) than if only location (4.0%) or response (5.2%) was repeated.

Discussion

In experiment 4, R1 was performed before the onset of S1 in most trials. This rules out any stimulus- or correspondence-related problems in R1 selection, that is, S1-R1 correspondence effects on R1 could not occur since S1 occurred after R1. Nevertheless, the results look much like those from experiment 2, where S1-R1 correspondence effects were obtained. As shown in Fig. 3, the effects of S2-R2 correspondence are virtually identical to those observed in experiment 2, including their variation with S1-R1 correspondence. That is, selection conflicts arising from S1-R1 noncorrespondence are unlikely to be responsible for the interaction between S1-R1 correspondence and S2-R2 correspondence. More likely candidates are the feature-integration processes, which also produced a result pattern very similar to that of experiment 2 (see Fig. 4). In fact, the only difference is that the response-related effects are somewhat smaller in experiment 4. However, as this is true of the benefits of both complete and partial repetitions, the cause of this difference does not seem to be related to integration.

General discussion

This study investigated the finding that the Simon effect occurs only when the S-R locations on the preceding trial corresponded (e.g., Mordkoff, 1998; Stürmer et al., 2002). Experiment 1 replicated the basic pattern of results in a two-pair S1-R1/S2-R2 design: pronounced Simon effects were obtained for the second response if it followed a corresponding S1-R1 pair, but not if it followed a noncorresponding S1-R1 pair. In experiment 2, R1 was cued in advance in order to minimize S1-induced conflicts in response selection, and yet standard S2-R2 Simon effects were again observed only after corresponding S1-R1 pairs. However, because Simon effects were obtained for S1-R1, it could not be ruled out that response-selection difficulties were again responsible for the interaction between S1-R1 and S2-R2 correspondence. In experiment 3, therefore, no response was required to S1, so that S1-R1 correspondence could not be affected by the selection of R1. Nevertheless, the effects of S2-R2 correspondence were again found to depend on the correspondence between S1 and the implied R1. The same was true in experiment 4, although S1 was presented after performance of R1 and therefore could not produce S1-R1 Simon effects.

Mordkoff (1998) and Stürmer et al. (2002) suggest that gating/suppression of the unconditional, automatic route occurs as a consequence of mechanisms that resolve response conflict in a noncorresponding trial. Stürmer et al. based their explanation on Kornblum et al.'s (1990) dual-route model of S-R compatibility, proposing that a monitoring process detects and resolves conflict between the responses activated by the unconditional and conditional routes. According to their explanation, "Following a response conflict, the monitoring system may send a control signal that blocks transmission of the output of the unconditional route to the motor execution system" (p. 1362). The results of the present study, taken together, make it clear that the sequential dependencies of the Simon effect do not depend on the selection of R1, that is, on the preceding response. This rules out models such as that proposed by Stürmer et al., which assume a crucial role of response selection or any other process having to do with control of overt action. This point has important implications for the idea of information gating or route suppression. If gating or suppression were an internal reaction to difficulties in response selection, one might consider this to be a rather adaptive process: the system might learn to make more or less use of "automatically" available information, depending on how helpful this information turned out to be in a given situation. However, given the present evidence that response-selection difficulties are not a necessary requirement, this version of the gating/suppression hypothesis is unlikely to be correct.

Although Stürmer et al. (2002) concluded that suppression was due to voluntary action control processes, aspects of their results also suggest that it is not. In their experiments 1 and 2 specifically, the relative frequency of corresponding trials within a given block was varied, being 20% or 80% (a 50% condition was also included in experiment 1). In agreement with other studies (e.g., Hommel, 1994; Marble & Proctor, 2000), the magnitude of the Simon effect varied as a function of the relative frequency of corresponding and noncorresponding trials, being much larger when corresponding trials predominated than when noncorresponding trials did (averaging 69 and −3 ms respectively across both experiments). However, the qualitative pattern of sequential effects was similar for the different relative frequencies: A large positive Simon effect was evident when the previous trial was corresponding, and absent when it was noncorresponding, for all relative frequency conditions. Moreover, the positive Simon effect following corresponding trials when the proportion of corresponding trials was 20% was of a similar magnitude to when it was 50%, and the elimination of the Simon effect following noncorresponding trials when the proportion of noncorresponding trials was 20% was equally as evident as when it was 50%. In terms of the gating/suppression hypothesis, this suggests that the mechanism causing the sequential effects is not under the subject's control because it is unlikely that subjects would continue to activate the automatic route following a corresponding trial when noncorresponding trials predominate, and to suppress the automatic route following a noncorresponding trial when corresponding trials predominate.

Therefore, to save the gating/suppression view, one would need to assume that gating/suppression as such is a rather automatic consequence of conflict. In particular, three assumptions have to be made. First, it would be necessary to assume that perceiving a stimulus leads to automatic activation of the spatially corresponding response *even if a response is preselected or no response is carried out at all.* This assumption is quite reasonable but inconsistent with models that make the time point of translating the irrelevant spatial code into response activation contingent on the transfer of relevant stimulus information to the response system, such as the dimensional-overlap model of Kornblum, Stevens, Whipple, and Requin (1999) on which Stürmer et al. (2002) based their account. This model claims that "activation in the irrelevant stimulus module is allowed to start acting on the activation function in the response module via S-R automatic processing lines" only if the "controlled line begins sending an input value of 1 to the response unit designated by the task" (Kornblum et al., 1999, p. 699). Thus, in the absence of relevant information transfer, no irrelevant information is transferred. As no relevant stimulus information needed to be transferred to response systems in experiments 2–4, because the response was already known or did not need to be carried out, this means that no irrelevant information should have been transferred either. If so, however, it would be hard to see how any conflict should have occurred. Yet without any conflict the very idea of information gating and route suppression makes very little sense.

Second, and related to this, the outcome of experiment 3 would need to be accounted for by assuming that relevant stimulus information is translated into an arbitrarily mapped response *even if that response is unnecessary and not (to be) carried out*. Again, this assumption is reasonable and consistent with findings from dual-task studies (Hommel, 1998b) but does not seem to fit with the most-cited dual-route approach, Kornblum et al.'s (1999) dimensional-overlap model. According to this model, arbitrary mappings between stimuli and responses are processed via a controlled route. Inasmuch as the term "controlled" is taken to refer to the intention of the perceiver/actor, it does not seem to fit with the assumption of an unnecessary translation of S1 into R1 in experiment 3.

The third assumption necessary for a tenable gating/suppression model is that the mere activation of more than one response at a time (in the incompatible conditions of experiments 3 and 4) is sufficient to produce gating or suppression. Although such a mechanism is possible, it does not seem very plausible because the purpose of this mechanism is difficult to envision. Moreover, assuming gating or suppression under such conditions implies a rather sophisticated mechanism that not only needs to detect a response conflict but also to evaluate the relative contributions to this conflict of several sources of information. Otherwise, the mechanism could not decide what information to gate or what route to disable. Such a mechanism may exist, but this would rather increase the burden of explanation.

Although an automatic gating/suppression mechanism cannot be ruled out on the basis of current evidence, an account in terms of stimulus- and response-feature integration (Hommel, 1998a) provides a powerful alternative. If one accepts the alternative treatment and analyses of the data, Fig. 4 shows that evidence consistent with the integration of stimulus form and stimulus location was obtained in all four experiments. As already mentioned, given the perfect correlation between stimulus form (signaling the response) and response location (being signaled by form), these effects are likely to represent the combination of form-location and form-response integration effects. This suggests that the effects of integrating stimulus form and stimulus location are overestimated in experiments 1 and 3. Indeed, the analogous effects were much smaller in experiments 2 and 4, and in Hommel's (1998a) study, where stimulus form and response location were unconfounded. Most importantly, if one accepts the presence of these integration effects in the experiments of this study, there is no further need to invoke any kind of information-gating or route-suppression hypothesis. Given that the analyses of correspondence and repetition effects were based on the same data, the effects shown in Fig. 4 are just another way of presenting the data shown in Fig. 3. Thus, if one is willing to attribute the patterns in Fig. 4 to feature-integration processes, no additional explanation is required for the patterns in Fig. 3 or the findings of Stürmer et al. (2002) and Mordkoff (1998).

The most obvious advantage of an integration account of sequential correspondence effects is that it keeps intact the common idea of parallel voluntary and automatic routes from stimulus to response stages, without any trial-to-trial modulation of the contribution of the automatic route. Notebaert et al. (2001) noted this point, indicating that if a binding account of the type advocated here is accepted, "the dual-route model as a working model for correspondence effect can still be used in its original form, that is, without control over the automatic response-priming route" (p. 183). In contrast, the assumption of gating "automatic" activation or suppressing "automatic" routes would stretch the concept of automaticity sufficiently far, even in the version that does not treat resolution of response-conflict as necessary, that giving up the automatic-route notion altogether seems to be the only acceptable consequence. These considerations, however, are not meant to imply that the concept of automatic routes is without problems, nor that it is impossible to reconcile the ideas of information gating or route suppression on the one hand and of feature integration on the other. In a recent review on the control of S-R translation, Hommel (2000) concluded that there is little evidence that effects commonly taken to indicate automatic response activation are completely independent of the task and the intentions of the performing person. Rather, it seems that preparing oneself for a task includes the implementation of S-R translation rules that act in a reflex-like fashion once the predefined stimulus appears (see also Bargh, 1989; Neumann & Prinz, 1987). In the case of the Simon effect, automatic S-R translation may depend on the actor's preparation to perform particular spatial responses to particular stimuli. Indeed, Valle-Inclán and Redondo (1998) observed stimulus-induced lateralized readiness potentials—electrophysiological indicators of automatic response activation—only if participants already knew which stimulus-response mapping was valid for the current trial, but not if the stimulus preceded the presentation of the mapping. This result suggests that, in a sense, even response activation is willed. Nevertheless, once a route is implemented, translation proceeds automatically.

The feature integration account is consistent with several recent findings. Notebaert and Soetens (2003) recently reported two experiments that examined repetition effects for four colors mapped to two key press responses, allowing stimulus and response repetition effects to be separated. Their experiment 1 used a Simon task for which stimulus location was irrelevant, and their experiment 2 used a similar task in which the shape of a centered stimulus (e.g., X or O) was the irrelevant dimension. In both experiments, the conjunction of stimulus and response affected performance in the manner suggested by the feature integration account. Thus, RT was shortest when both stimulus features repeated or when both changed. Note that the repetition effects occurred in a situation that does not yield a Simon effect (experiment 2), as well as one that does (experiment 1), which poses problems for the suppression hypothesis. Although the effect was larger when location was irrelevant than when shape was irrelevant, this difference in magnitude is likely due to the similarity of the irrelevant location dimension with the response dimension. Consistent with this interpretation, Hommel (2003) found that repeating stimulus location increased the tendency to repeat the response when the responses were left-right key presses but not when they were single or double key presses.

The feature integration account can also explain the results of studies in which Simon trials were intermixed with trials for which stimulus location was relevant (Proctor & Vu, 2002; Proctor, Vu, & Marble, 2003). In those experiments, the magnitude of the Simon effect was affected by the mapping that was in effect for the location-relevant trials. Specifically, relative to a control condition in which Simon trials were presented in pure blocks, the Simon effect was enhanced when the location-relevant mapping was compatible and reversed when it was incompatible. Analysis of sequential effects showed that, independent of the overall Simon effect obtained for each condition, the Simon effect varied systematically as a function of the previous trial type. In pure blocks of Simon trials, the sequential effects obtained with the correspondence and repetition analyses were similar to those reported in the present article. In the correspondence analysis, a positive Simon effect was obtained when the previous trial was corresponding, and a reverse Simon effect was obtained when the previous trial was noncorresponding. In the repetition analysis, responses were faster when the stimulus features both repeated or changed than when only one did.

In mixed blocks, the correspondence analysis showed that the Simon effect was positive when the previous trial was corresponding and reversed when the previous trial was noncorresponding, regardless of whether the location-relevant mapping was compatible or incompatible. In other words, variation in the magnitude of the Simon effect as a function of the correspondence relation on the previous trial was independent of the overall mean Simon effect, which was positive when the location-relevant mapping was compatible and negative when it was incompatible. Thus, the mixed conditions showed similar repetition patterns, with the major effect of an incompatible location-relevant mapping, as opposed to a compatible mapping, shifting the overall level to more negative. The repetition analysis showed that responses were faster when both stimulus features were repeated than when only one feature was, as in the pure blocks of Simon trials, but there was no benefit of having both stimulus features change. This outcome would be expected on the basis of the feature integration account because, in this case, a complete change does not unambiguously signal that the alternative response from the previous trial is to be made.

A similar independence of the pattern of repetition effects from the mean compatibility effects is evident in studies for which compatible and incompatible location-relevant mappings are mixed. Vu and Proctor (2003) conducted two experiments in which left-right physical locations, arrow directions, or location words were mapped compatibly and incompatibly to left-right key presses (experiment 1) or spoken responses (experiment 2), with the mapping for a trial designated by color stimulus. With key press responses, the compatibility effect was eliminated by mixing mappings for physical locations and arrow directions, but was increased substantially for location words. With vocal responses, the compatibility effect was reduced by mixing location words but not physical locations and arrows. Although mixing affected the compatibility effects differently within and between response modalities, a similar pattern of repetition effects was evident in all cases. This finding is in agreement with the implication that the feature integration process responsible for the pattern of repetition effects is distinct from the processes producing the mean effects.

In summary, the present study demonstrates that gating/suppression of the automatic response-selection route is not the only possible explanation of the sequential variation in the Simon effect. The feature-integration account provides an alternative interpretation that does not imply trial-to-trial changes in activation of the corresponding response via the automatic route and readily accounts for many findings. Even if gating/suppression is responsible for the sequential effects, our results suggest that this process is not under voluntary control.

Acknowledgements We would like to thank Anke Bogatzky, Patrizia Falkenberg, Alexandra Heinrich, Nicola Korherr, Manuela Mench, Heike Mittmann, Edith Müller, Anke Schlender, and Christian Seidel for collecting the data; Thierry Hasbroucq, Sylvan Kornblum, Wilfried Kunde, and Hartmut Leuthold for comments on previous drafts of this paper; and Heidi John for assistance in preparing the manuscript.

References

Bargh, J. A. (1989). Conditional automaticity: varieties of automatic influence in social perception and cognition. In J. S. Uleman, & J. A. Bargh (Eds.), *Unintended thought* (pp. 3–51). London: Guilford Press.

De Jong, R. (1995). Strategical determinants of compatibility effects with task uncertainty. *Acta Psychologica*, *88*, 187–207.

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: a dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 731–750.

Dutzi, I. B., & Hommel, B. (2003). *Spontaneous but goal-dependent binding of actions and their effects*. Manuscript submitted for publication.

Hommel, B. (1993). The relationship between stimulus processing and response selection in the Simon task: evidence for a temporal overlap. *Psychological Research*, *55*, 280–290.

Hommel, B. (1994). Spontaneous decay of response-code activation. *Psychological Research*, *56*, 261–268.

Hommel, B. (1995). Stimulus-response compatibility and the Simon effect: toward an empirical clarification. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 764–775.

Hommel, B. (1996). S-R compatibility effects without response uncertainty. *Quarterly Journal of Experimental Psychology*, *49A*, 546–571.

Hommel, B. (1998a). Event files: evidence for automatic integration of stimulus-response episodes. *Visual Cognition*, *5*, 183–216.

Hommel, B. (1998b). Automatic stimulus-response translation in dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1368–1384.

Hommel, B. (1998c). *Binding between perceptual objects and action plans: the temporal dynamics of event-file construction*. Presentation on the 10th Conference of the European Society for Cognitive Psychology. Jerusalem, September.

Hommel, B. (2000). The prepared reflex: automaticity and control in stimulus-response translation. In S. Monsell, & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 247–273). Cambridge, MA: MIT Press.

Hommel, B. (2003). *Feature integration across perception and action: event files affect response choice*. Manuscript submitted for publication.

Hommel, B., & Colzato, L. S. (2003). *Visual attention and the temporal dynamics of feature integration*. Manuscript submitted for publication.

Hommel, B., & Eglau, B. (2002). Control of stimulus-response translation in dual-task performance. *Psychological Research*, *66*, 260–273.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): a framework for perception and action planning. *Behavioral and Brain Sciences*, *24*, 849–937.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: object-specific integration of information. *Cognitive Psychology*, *24*, 175–219.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: cognitive basis for stimulus-response compatibility—a model and taxonomy. *Psychological Review*, *97*, 253–270.

Kornblum, S., Stevens, G. T., Whipple, A., & Requin, J. (1999). The effects of irrelevant stimuli. I. The time course of stimulus-stimulus and stimulus-response consistency effects with Stroop-like stimuli, Simon-like tasks, and their factorial combinations. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 688–714.

Logan, G. D., & Gordon, R. D. (2001). Executive control of visual attention in dual-task situations. *Psychological Review*, *108*, 393–434.

Logan, G. D., & Schulkind, M. D. (2000). Parallel memory retrieval in dual-task situations. I. Semantic memory. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 1072–1090.

Lu, C.-H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: a review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review*, *2*, 174–207.

Marble, J. G., & Proctor, R. W. (2000). Mixing location-relevant and location-irrelevant choice-reaction tasks: influences of location mapping on the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 1515–1533.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1423–1442.

Mordkoff, T. (1998). The gating of irrelevant information in selective-attention tasks [Abstract]. *Abstracts of the Psychonomic Society*, *3*, 193.

Neumann, O., & Prinz, W. (1987). Kognitive Antezedenzien von Willkürhandlungen [Cognitive antecedents of voluntary actions]. In H. Heckhausen, & F. E. Weinert (Eds.), *Jenseits des Rubikon: der Wille in den Humanwissenschaften* (pp. 195–215). Berlin Heidelberg New York: Springer.

Notebaert, W., & Soetens, E. (2003). The influence of irrelevant stimulus changes on stimulus and response repetition effects. *Acta Psychologica*, *112*, 143–156.

Notebaert, W., Soetens, E., & Melis, A. (2001). Sequential analysis of a Simon task-evidence for an attention-shift account. *Psychological Research*, *65*, 170–184.

Praamstra, P., Kleine, B.-U., & Schnitzler, A. (1999). Magnetic stimulation of the dorsal premotor cortex modulates the Simon effect. *Cognitive Neuroscience and Neuropsychology*, *10*, 3671–3674.

Proctor, R. W., & Vu, K.-P. L. (2002). Eliminating, magnifying, and reversing spatial compatibility effects with mixed location-relevant and irrelevant trials. In W. Prinz, & B. Hommel (Eds.) *Common mechanisms in perception and action: Attention and Performance XIX* (pp. 443–473). Oxford: Oxford University Press.

Proctor, R. W., Vu, K.-P. L., & Marble, J. G. (2003). Mixing location-relevant and irrelevant tasks: spatial compatibility effects eliminated by stimuli that share the same spatial codes. *Visual Cognition*, *10*, 15–50.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207–231.

Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor, & T. G. Reeve (Eds.), *Stimulus-response compatibility* (pp. 31–86). Amsterdam: Elsevier.

Stoet, G., & Hommel, B. (1999). Action planning and the temporal binding of response codes. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1625–1640.

Stoffels, E. J. (1996). On stage robustness and response selection routes: further evidence. *Acta Psychologica*, *91*, 67–88.

Stürmer, B., Leuthold, H., & Sommer, W. (1998). Strategische Effekte und kurzfristige Modulationen im Simon-Paradigma [Strategic effects and short-term modulations in the Simon paradigm] [Abstract]. In H. Lachnit, A. Jacobs, & F. Rösler (Eds.), *Experimentelle Psychologie: Abstracts der 40. Tagung experimentell arbeitender Psychologen* (pp. 365–366). Lengerich: Pabst Science Publishers.

Stürmer, B., Leuthold, H., Soetens, E., Schröter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task: behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 1345–1363.

Valle-Inclán, F., & Redondo, M. (1998). On the automaticity of ipsilateral response activation in the Simon effect. *Psychophysiology*, *35*, 366–371.

Valle-Inclán, F., Hackley, S. A., & de Labra, C. (2002). Does stimulus-driven response activation underlie the Simon effect? In W. Prinz, & B. Hommel (Eds.), *Common mechanisms in perception and action: Attention and Performance XIX* (pp. 474–493). Oxford: Oxford University Press.

Vu, K.-P. L., & Proctor, R. W. (2003). *Elimination and enhancement of spatial compatibility effects with mixed mappings*. Manuscript submitted for publication.