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Precueing Spatial S-R Correspondence: Is There Regulation of Expected Response Conflict?

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Four experiments investigated the ability to prepare for the level of forthcoming stimulus–response correspondence in choice-response tasks. In a Simon task, participants responded to the color of spatially variable stimuli with spatially variable responses. Participants were given advance information about whether a forthcoming stimulus–response event would be spatially corresponding, neutral, or spatially noncorresponding. Reliable cues decreased reaction times (RTs) in the corresponding conditions of 2- and 3-choice tasks, decreased RTs in noncorresponding conditions of a 2-choice task but not in a 3-choice task, and left RTs in neutral conditions unaffected. The pattern of results suggests that participants used reliable cues for responding to the nominally irrelevant stimulus location if the correct response could be inferred from location (attention switching). By contrast, the lack of cueing effects on performance in noncorresponding conditions of 3-choice tasks suggests that participants cannot use cues for changing the attentional weights of processing channels for different stimulus dimensions (gating). In summary, gating may be involved in the regulation of experienced response conflict, but the present results suggest that it is not involved in the regulation of expected (i.e., predicted) response conflict.

Keywords: attention switching, cueing, response conflict, conflict regulation, Simon effect

In everyday situations, people often perceive several objects that are associated with different actions. Perception of these different objects simultaneously activates several *affordances*, or action concepts. For example, in the very same moment, perception of the computer keyboard on one's desktop may afford working on a manuscript, perception of the coffee cup may afford grasping it, and the perception of the newspaper may afford reading it. In such situations, people experience response conflict. An important cognitive function is the ability to resolve response conflict, and to choose the most adequate response among a variety of simultaneously possible opportunities.

Cognitive psychologists investigate the mechanisms involved in resolving response conflict in interference tasks. In such tasks, participants have to perform a response that has been assigned to a relevant stimulus, and to inhibit responses assigned to, or associated with, irrelevant stimulation. In the Simon task, for example, participants have to perform a spatial response to a nonspatial stimulus attribute (e.g., color), and the correspondence between the irrelevant stimulus location and the response location is varied (e.g., Simon, 1968). Reaction times (RTs) are shorter when the irrelevant stimulus location and the response location correspond (e.g., stimulus left, response left) than when they do not correspond (e.g., stimulus left–response right; see Proctor & Vu, 2006, for a review). Typically, interference effects are explained by assuming that irrelevant stimulation activates responses either on the basis of task instructions or on the basis of long-term associations, and these responses interfere with selection of the correct response.

Interestingly, the amount of interference from irrelevant stimulation (reflecting response conflict) varies as a function of recent experience. Specifically, the experimental condition in the preceding trial affects the size of interference effects in the present trial. Large interference effects are typically found after congruent (or compatible) trials, whereas interference effects are reduced or absent after incongruent (or incompatible) trials. This pattern has been observed for the Simon task (e.g., Praamstra, Kleine, & Schnitzler, 1999; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002), as well as for other interference tasks such as the Eriksen task (e.g., Gratton, Coles, & Donchin, 1992) and the Stroop task (e.g., Kerns et al., 2004). For some researchers, the sequential modulations of interference effects point to the existence of a cognitive mechanism that detects and regulates response conflicts (e.g., Botvinick, Cohen, & Carter, 2004; Kunde & Wühr, 2006; Stürmer et al., 2002). For example, Stürmer et al. (2002) proposed a conflict-regulation mechanism that registers the amount of response conflict and regulates the access of irrelevant stimulation to the response system (e.g., Stürmer & Leuthold, 2003; Stürmer et al., 2002). In particular, Stürmer et al. assumed that the conflict-regulation mechanism decreases the ability of irrelevant stimulation to access the response system after spatially noncorresponding conditions. As a result, interference effects are

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small (or absent) after spatially noncorresponding conditions compared to spatially corresponding conditions.

Subsequent work on the Simon effect showed that, when compared to an appropriate neutral condition, interference effects are not only decreased after spatially noncorresponding conditions, but also increased after spatially corresponding conditions (Leuthold & Schröter, 2006; Wühr & Ansorge, 2005). Therefore, it has been proposed that the connection between irrelevant stimulation and the response system may usually have intermediate "conductivity," and the conductivity may be decreased after spatially noncorresponding conditions and increased after spatially corresponding conditions. In other words, current accounts of conflict regulation (in the Simon task) assume that participants can set the attentional weight for the processing of the irrelevant (location) information in a gradual manner. This process is sometimes called *gating* (e.g., Mordkoff, 1998).

Research in recent years has focused on *reactive* regulation of response conflict, that is, on how experience of response conflict at time N affects the amount of response conflict at time $N + 1$. By contrast, the present study was concerned with the possibility of *anticipatory* control of response conflict. In particular, we were interested in whether participants are able to decrease (or eliminate) the processing of nominally irrelevant information when they are expecting conflict. There are only a few previous studies that investigated whether participants can use advance information about the compatibility level in the upcoming trial for adjusting their processing system (Gratton et al. 1992; Logan & Zbrodoff, 1982). The results of these studies suggest that participants can use advance information about the congruency of irrelevant stimulation for improving performance, but the mechanisms behind these improvements remained unclear, as will be explained later.

When one studies anticipatory control of response conflict, three important questions have to be considered. First, what measure of response conflict should be considered? The typical measure of response conflict is the correspondence (or congruency) effect, that is, the difference between performance in a corresponding (or congruent) condition and performance in a noncorresponding (or incongruent) condition. Hence, one might wish to compare correspondence effects following uninformative cues (that provide no information about the next level of stimulus–response [S-R] correspondence) to correspondence effects following informative cues (that provide information about the next level of S-R correspondence). This comparison, however, is likely to be inconclusive. The reason is that preparation for corresponding displays might increase benefits, whereas preparation for noncorresponding displays might decrease costs, as suggested by Wühr and Ansorge (2005). Therefore, if the increase of benefits and the decrease of costs are of similar size, the overall correspondence effect with informative cues will be similar to correspondence effects with uninformative cues, as it was observed by Stürmer (2005). A second strategy might be to introduce a neutral condition (with respect to S-R correspondence) and to assess the effects of informative cues on performance benefits and costs relative to that neutral condition. This approach appears useful because it allows assessing whether preparation occurs to both corresponding and/or to noncorresponding events. Thus, we opted for assessing the effects of preparation on response conflict by analyzing the effects of informative cues on costs and benefits together with a careful analysis of absolute RTs (see also Jonides & Mack, 1984).

The second question that should be considered before investigating anticipatory control of response conflict is, How can we distinguish between different ways for dealing with expected conflict? Two means for anticipatory conflict regulation are apparent. The first possibility, *gating*, involves gradual adjustments of the conductivity of processing channels for relevant and irrelevant stimulus information. In particular, the attentional weight for the processing of irrelevant information might increase when a corresponding (or congruent) condition is expected, in order to exploit the redundant information from the irrelevant stimulus dimension. In addition, the attentional weight for the processing of irrelevant information might decrease and/or the attentional weight for the processing of relevant information might increase when the noncorresponding (or incongruent) condition is expected (Egner & Hirsch, 2005; Leuthold & Schröter, 2006; Wühr & Ansorge, 2005). However, an alternative means might be to use the cues for *switching attention* from the nominally relevant to the nominally irrelevant stimulus dimension, and respond to the latter. Whereas gating assumes that the impact of the irrelevant information is modified according to its usefulness while relevant information is still processed, the attention switching account assumes that participants base their responses intentionally on the irrelevant dimension and ignore the nominally relevant information outright. Obviously, gating and attention switching are not mutually exclusive. In particular, *attention switching* means to assign attentional weights in an all-or-none fashion (e.g., 0% location vs. 100% color, or 100% location vs. 0% color), whereas *gating* means to assign attentional weights in a graded fashion (e.g., 50% vs. 50%).

To illustrate this point, we ask the reader to consider a study by Logan and Zbrodoff (1982). These authors investigated attention switching in a Stroop task. Participants had to read one of two position words (*above* or *below*) that randomly appeared above or below fixation, and the congruency in the next trial was cued. There were two interesting results. Reliable congruency cues decreased RTs relative to an uninformative cue, both for congruent and for incongruent stimuli, and the RT decrease was larger for congruent stimuli. Logan and Zbrodoff suggested that valid cues prompted participants to switch attention from the relevant stimulus dimension (word meaning) to the more easily accessible irrelevant dimension (word location). It was concluded that cues to congruent conditions prompted participants to respond compatibly to stimulus location, whereas cues to incongruent conditions prompted them to respond incompatibly to stimulus location. Note, however, that the results could also be explained in terms of gating. Word meaning and word location might be processed in parallel, but participants might increase the attentional weight for location processing when expecting a congruent display, and decrease the weight when expecting an incongruent display (Leuthold & Schröter, 2006; Wühr & Ansorge, 2005).

Fortunately, it is possible to distinguish between attention switching and gating by varying the number of response alternatives in a task. In particular, switching attention to the irrelevant stimulus dimension and gating are both applicable with cues predicting corresponding conditions. Moreover, both strategies are available in noncorresponding conditions of two-choice tasks, when participants might either respond incompatibly to the irrelevant stimulus location and/or focus more strongly on the relevant stimulus feature. By contrast, only gating, but not attention switching, is applicable with cues predicting noncorresponding conditions in a three-choice task (or in any other task with more than two possible responses). Specifically, attention switching is not available in noncorresponding conditions of a three-choice Simon task because there are two noncorresponding response locations for each stimulus location. Hence, if we observe that informative cues affect performance in noncorresponding conditions of two-choice and of three-choice tasks, we would be tempted to conclude that gating, in order to avoid response conflict, is possible. If, however, we observe that informative cues affect performance in noncorresponding conditions of two-choice tasks only, we should conclude that attention switching is applicable, whereas gating is not.

Finally, the third question that should be considered before investigating anticipatory control of response conflict is, How should we inform participants about S-R correspondence in the next trial? Two possibilities are available. The first possibility is to use unreliable cues, and to compare performance with valid cues to performance with invalid cues. The second possibility is to compare performance with reliable cues (i.e., informative cues that are always valid) to performance with unspecific cues (i.e., uninformative regarding the S-R correspondence level).

Gratton et al. (1992) used unreliable cues to inform participants about the compatibility level in the next trial of an Eriksen task. That is, an informative cue indicating compatible or incompatible displays was valid in 80% of the cases, and invalid in 20% of the cases. Interestingly, the impact of flanker compatibility was increased after cues predicting compatible trials, as compared to the remaining conditions, because RTs to compatible displays were especially fast after valid cues. In contrast, flanker-interference effects were similar with cues predicting incompatible trials and with neutral cues. Gratton and colleagues concluded that the expectation of compatible trials led participants to rely on parallel stimulus processing (i.e., respond to any stimulus), whereas the expectation of neutral or incompatible trials led participants to rely on focused stimulus processing (i.e., respond to the central stimulus only). Thus, they proposed a form of gating. Several alternative accounts are possible, however. First of all, because Gratton and colleagues used a two-choice task, it is possible that cues predicting compatible displays prompted participants to respond to the flankers instead of responding to the target, which could improve performance because there were more flankers than targets in the display. Thus, attention switching would explain the results as well. Second, invalidly cued trials were rare events. It is therefore possible that the mere surprise to see an incompatible display after a cue predicting a compatible display impairs performance, apparently increasing interference effects with compatible cues. Similarly, the mere surprise to see a compatible display after a cue predicting an incompatible display impairs performance, apparently decreasing interference effects with compatible cues. Third, it is possible that more practice with compatible cues followed by compatible displays than with compatible cues followed by incompatible displays increases congruency effects with compatible cues, whereas less practice with incompatible cues followed by compatible displays than with incompatible cues followed by incompatible displays decreases congruency effects with incompatible cues. From these considerations, we concluded that comparison of interference effects with reliable cues (i.e., cues predicting the upcoming S-R correspondence level with 100% accuracy) to interference effects with unspecific cues is preferable to the use of unreliable (i.e., valid and invalid) cues.

To summarize, the present study investigated possible mechanisms of anticipatory conflict regulation by exploring the effects of informative S-R correspondence cues on performance in two-choice and in three-choice Simon tasks. We employed a two-choice task in Experiment 1 to explore whether preparation effects in the Simon task could be observed at all. As it turned out, there were reliable effects of precueing the compatibility level. Experiments 2, 3, and 4 then used three-choice Simon tasks where gating, but not attention switching, is applicable with cues predicting noncorresponding conditions.

Experiment 1

Experiment 1 explored the effects of reliable S-R correspondence cues on performance in a two-choice Simon task. Participants had to respond to the color of an imperative stimulus by pressing a left or right key. We varied spatial correspondence between stimulus and response location, such that the stimulus randomly appeared at the corresponding, at the neutral, or at the noncorresponding location (cf. Figure 1). In one part of the experiment, participants did the Simon task without advance information about spatial S-R correspondence in the next trial. In another part of the experiment, participants were given reliable cues about spatial S-R correspondence before each trial. We examined the effects of reliable cues on RTs in corresponding and noncorresponding conditions, and the effects of reliable cues on the cost–benefit pattern, in comparison to the results with unspecific cues. As already said in the introduction, Experiment 1 investigated whether reliable S-R correspondence cues would have any effects at all, without already clarifying whether attention switching or gating is applied. If participants prepare on the basis of reliable cues, we expected to see that these cues decrease RTs in corresponding and in noncorresponding conditions (e.g., Logan & Zbrodoff, 1982). Moreover, we expected to also see that reliable cues increase benefits from corresponding events and/or decrease

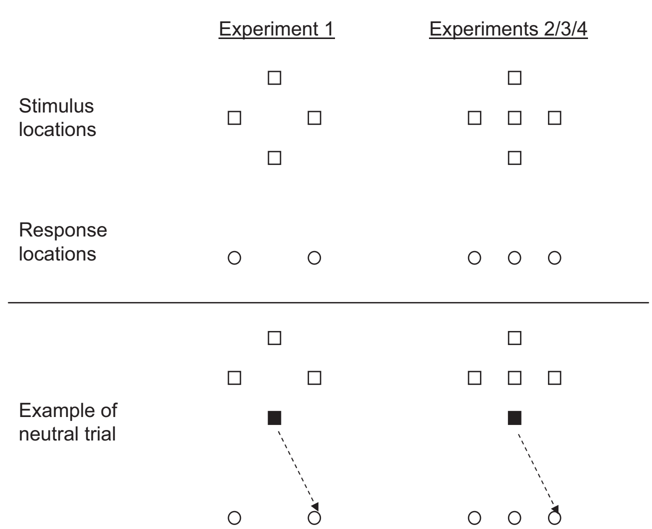

Figure 1. Spatial layout of stimuli and responses in the present experiments.

costs from noncorresponding events, when compared to conditions with unspecific cues.

Method

Participants. Forty volunteers (students from Friedrich-Alexander Universität: 30 women, 10 men) with a mean age of 23 years (range = 19–32 years) participated for payment (5€) or course credit. In this and the following experiments, participants were naive with respect to the purpose of the study and classified themselves as having normal (or corrected-to-normal) visual acuity.

Apparatus and stimuli. Participants sat in front of a 17-in. (43.18-cm) color monitor, with an unconstrained viewing distance of approximately 50 cm. An IBM-compatible computer controlled the presentation of stimuli and collected keypress responses on a standard keyboard. Visual stimuli were shown on a black background. The fixation point was a small + (0.3° of visual angle). A cue consisted of one of the four German words *Achtung* (*attention*), *Neutral* (*neutral*), *Kompatibel* (*compatible*), or *Inkompatibel* (*incompatible*). The words subtended between 0.9° × 4.6° (*Achtung*) and 0.9° × 7.0° (*Inkompatibel*). The cues were presented in yellow color. The imperative stimuli were filled squares with a side length of 1.2°. The squares appeared in red or green color at one of four positions. Stimulus positions were 5.5° to the left, right, above, or below the screen center. Participants responded by pressing the left or right control key on the computer keyboard.

Procedure. The experiment included 10 blocks of trials, 5 blocks with an unspecific cue (*attention*) and 5 blocks with reliable cues (*compatible*, *incompatible*, or *neutral*). Half of the participants performed the task with unspecific cues before doing the task with reliable cues. The other half of participants performed the two cueing conditions in reverse order. Separate instructions were given before the blocks with unspecific cues and before the blocks with reliable cues. In the former case, instructions told participants that the word *attention* would precede each imperative stimulus as a warning signal. In the latter case, instructions described the three experimental conditions (corresponding, neutral, and noncorresponding conditions) to the participants and informed them that a valid cue would precede each imperative stimulus. Moreover, participants were told to use these cues, without telling them exactly what to do. In addition, the instructions always described the stimuli and the sequence of events in a typical trial. Finally, participants were informed about the mapping of stimulus colors onto response keys.

An experimental trial contained the following sequence of events. After a blank period of 800 ms the cue was presented for 600 ms in the middle of the screen. Next, a fixation point replaced the cue and remained alone for 600 ms. Then the square appeared at one of four locations, and remained together with the fixation point until response onset. Thus, the stimulus onset asynchrony (SOA) between cue onset and square onset was 1,200 ms. RTs were measured from the onset of the square for a period of 1,000 ms. If the response was correct, the next trial started immediately. If, however, the response was incorrect, or if RT was shorter than 100 ms or longer than 800 ms, a corresponding error message was shown in white color for an additional 2 s at screen center.

For each cueing condition, participants performed one practice block of 38 trials, and four experimental blocks of 62 trials. During practice, the experimenter was present in the lab room and watched the participant in order to see whether she/he was doing it right. Moreover, the presence of the experimenter during practice enabled participants to ask questions if some detail of the task was unclear. The first two trials in each block were warm-up trials and not further analyzed. Participants could take a rest between two blocks, and started the next block at leisure. The whole experiment took about 30 min. After completion of the experiment, participants were asked whether they encountered any difficulties during the experiment, and whether they had noticed anything special.

Design. Experiment 1 rested on a 3 × 2 within-subjects design. The first factor was spatial S-R correspondence. Stimulus position was corresponding, neutral, or noncorresponding with respect to the position of the to-be-pressed key. In the neutral condition, the square appeared above fixation for 50% of the cases, and below fixation for the other 50% of the cases. The three correspondence conditions were equally frequent in each block of experimental trials (i.e., 20). The second factor was cueing condition. An unspecific cue (the word *attention*) or a reliable cue (one of the words *compatible*, *neutral*, or *incompatible*) preceded the imperative stimulus. The reliable cue informed the participants about spatial S-R correspondence in the following trial, but did not convey information regarding the stimulus or the response in the next trial. Each type of reliable cue appeared equally frequent in each block of experimental trials.

Results

To eliminate outliers, we removed all RTs exceeding two standard deviations from the individual mean RT of each participant. Averaged across participants, 0.3% of trials with premature responses and 4.1% with delayed responses were excluded with unspecific cues; 0.4% of trials with premature responses and 4.3% of trials with delayed responses were excluded with reliable cues. Table 1 shows mean RTs and mean error percentages as a function of cueing condition and S-R correspondence, but collapsed across order of cueing conditions. Two-tailed t tests were used for planned comparisons in each experiment unless otherwise noted. Finally, for each pairwise comparison, we report Cohen's d (Cohen, 1988) as a measure of effect size. We computed d according to the following formula:

$$d = t \times \sqrt{\frac{1}{N}}$$

By convention, d values around .20 are considered small (weak) effects, d values around .50 are considered intermediate effects, and d values around .80 (and larger) are considered large (strong) effects (e.g., Cohen, 1988).

RTs. RTs from error-free trials were subjected to a two-factorial analysis of variance (ANOVA), with cueing and S-R correspondence as within-subjects factors. The main effect of cueing was not significant, $F(1, 39) = 2.85$, $MSE = 777$, $p = .10$. By contrast, the main effect of S-R correspondence was significant, $F(2, 78) = 122.12$, $MSE = 195$, $p < .001$, indicating a Simon effect. Spatially corresponding conditions produced shortest RTs (395 ms), spatially neutral conditions produced intermediate RTs (423 ms), and spatially noncorresponding conditions produced longest RTs (426 ms). Finally, the two-way interaction between

Table 1
Reaction Times (RTs) and Percentages of Errors (PEs), Observed in Experiment 1 (N = 40), as a Function of Spatial Stimulus–Response Correspondence and Cue Type

	Cue type							
	Unspecific cue				Reliable cue			
	RT		PE		RT		PE	
Stimulus–response correspondence	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Corresponding	401	45	2.3	2.8	389	52	3.4	3.8
Spatially neutral	420	46	2.8	3.2	426	47	4.7	3.3
Noncorresponding	433	47	4.4	3.8	420	57	4.4	3.4
Benefit	19* (1.58)		0.5 (0.15)		37* (1.58)		1.3 (0.25)	
Cost	13* (1.36)		1.6* (0.42)		−6 (0.27)		−0.3 (0.05)	

Note. Also shown are benefits (neutral − corresponding conditions) and costs (noncorresponding − neutral conditions) in RTs and PEs. The values in parentheses are Cohen's *d*s, a measure of effect size.
* $p < .05$.

cueing and S-R correspondence was significant, $F(2, 78) = 17.38$, $MSE = 127$, $p < .001$. The interaction indicated that cues affected RTs in the three correspondence conditions differently. RTs in corresponding conditions and in noncorresponding conditions were faster with reliable cues than with unspecific cues: $t(39) = 3.08$, $p < .01$, $d = 0.49$, for corresponding conditions, and $t(39) = 2.44$, $p < .05$, $d = 0.39$, for noncorresponding conditions. By contrast, RTs in neutral conditions were somewhat slower with reliable cues than with unspecific cues, $t(39) = 1.89$, $p = .07$, $d = 0.30$.

Cost–benefit analysis of RTs. RT benefits from corresponding conditions (difference between neutral and corresponding conditions) were larger with reliable cues (difference = 37) than with unspecific cues (difference = 19 ms), $t(39) = 5.18$, $p < .001$, $d = 0.82$. In contrast, RT costs from noncorresponding conditions (difference between neutral and noncorresponding conditions) were smaller with reliable cues (difference = –6 ms) than with unspecific cues (difference = 13 ms), $t(39) = 4.39$, $p < .001$, $d = 0.69$. Interestingly, the overall Simon effects (noncorresponding minus corresponding RTs) were virtually identical with reliable cues (difference = 31 ms) and with unspecific cues (difference = 32 ms), $t(39) = 0.38$, $p = .71$, $d = 0.06$.

Errors. A two-factorial ANOVA was also performed on error percentages. The main effect of cueing was significant, $F(1, 39) = 10.59$, $MSE = 6.40$, $p < .01$, indicating more errors with cues (4.2%) than without (3.1%). Moreover, the main effect of S-R correspondence was also significant, $F(2, 78) = 4.52$, $MSE = 10$, $p < .05$, indicating a low error rate with corresponding conditions (2.9%), an intermediate error rate with neutral conditions (3.7%), and a high error rate with noncorresponding conditions (4.4%). In contrast to the RT results, the two-way interaction failed to reach significance, $F(2, 78) = 2.36$, $p = .10$, but the numerical pattern was similar to the RT results.

Discussion

The results of Experiment 1 show that participants used reliable S-R correspondence cues for preparing themselves to process the stimulus display in a two-choice Simon task. In particular, reliable S-R correspondence cues decreased RTs in corresponding and in noncorresponding conditions, compared to conditions with unspecific cues. These results nicely replicate results obtained by Logan and Zbrodoff (1982) with a two-choice version of the spatial Stroop task. Moreover, because cueing almost did not affect the neutral condition, reliable cues increased benefits from spatially corresponding conditions and decreased costs from spatially noncorresponding conditions, compared to a Simon task with unspecific cues. Notably, cueing did not affect the overall difference between corresponding and noncorresponding conditions, the usual measure of the Simon effect (Stürmer, 2005).

The results of Experiment 1 do not allow deciding between possible explanations for the observed effects of cueing S-R correspondence. Participants might have used the reliable cues either to respond on the basis of stimulus location instead of color, or they may have used the reliable cues to change the relative weights of processing channels for stimulus location and stimulus color. Both preparatory strategies are applicable in corresponding and noncorresponding conditions of two-choice tasks. To decide between the strategies, we needed conditions in which only one strategy is applicable. Such conditions were employed in Experiment 2.

Experiment 2

Experiment 2 investigated whether cueing S-R correspondence in a three-choice task reveals similar or different results than cueing S-R correspondence in a two-choice task. Participants had to respond to the color of an imperative stimulus by pressing one of three keys at different locations, and stimuli randomly appeared at corresponding, neutral, and noncorresponding locations (cf. Figure 1). Importantly, participants could still prepare themselves to respond exclusively on the basis of stimulus location when the corresponding condition was cued. Yet, this was impossible when the noncorresponding condition was cued. The reason is that stimulus location does not indicate the required response in noncorresponding conditions of a three-choice task. By contrast, when expecting a noncorresponding condition in a three-choice task, participants might be able to adjust the relative weights of processing channels for stimulus color and stimulus location, and regulate expected response conflict. Therefore, we were particularly interested to see whether cues predicting a noncorresponding condition would decrease RTs and performance costs in this condition. If this were the case, we would be tempted to conclude that gating for anticipatory regulation of response conflict is possible.

Method

Participants. Forty new volunteers (students from Universität Erlangen: 30 women, 10 men) with a mean age of 22 years (range = 19–37 years) participated for payment (5€) or course credit.

Apparatus and stimuli. A three-choice task was used in Experiment 2. Stimulus locations varied both on the horizontal dimension (4.5° to the left of screen center, at screen center, 4.5° to the right of screen center), and on the vertical dimension (4.5° above screen center, 4.5° below screen center). Stimulus positions on the vertical dimension were used as neutral stimulus locations. Response locations varied on the horizontal dimension only. Participants responded by pressing a left key (*4*), a central key (*5*), or a right key (*6*) on the numerical keypad of the keyboard. Responses were performed with the index, middle, and ring fingers of the right hand. Five outline boxes (1.8° × 1.8°) indicated the stimulus locations on the screen throughout an experimental trial. This was done because presenting imperative stimuli at screen center prevented the use of a fixation point. The imperative stimulus consisted of filling one of the five boxes with color (blue, green, red). There was one mapping of stimulus colors on the response keys for all participants (green–left, blue–center, red–right). The apparatus from Experiment 1 was used again.

Procedure. An experimental trial contained the following sequence of events. After a blank period of 800 ms the cue was presented for 600 ms in the middle of the screen. Next, five outline boxes appeared at the five possible stimulus locations and remained onscreen for 600 ms. Then, one of the boxes was filled with color, and the display remained onscreen until response onset. All other details of the procedure were identical to those of Experiment 1.

Half of the participants performed the Simon task with unspecific cues (six blocks; Block 1 was practice) before the Simon task with reliable cues (six blocks; Block 7 was practice). The other half of participants did the Simon task with reliable cues (six blocks) before the Simon task with unspecific cues (six blocks). The latter group of participants practiced the Simon task with unspecific cues in Block 1, then practiced the Simon task with reliable cues in Block 2, then performed five experimental blocks of the Simon task with reliable cues, and finally did five experimental blocks of the Simon task with unspecific cues. Each block contained 36 experimental trials plus two warm-up trials (which were not analyzed).

Design. Experiment 2 rested on a 3 (S-R correspondence) × 2 (cueing) within-subjects design. Each experimental block contained the same number of spatially corresponding, spatially neutral, and spatially noncorresponding conditions. This was achieved by presenting each corresponding display twice as often as each neutral and each spatially noncorresponding display.

Results

Averaged across participants, 0.6% of trials with premature responses and 4.1% of trials with delayed responses were excluded with unspecific cues; 0.7% of trials with premature responses and 3.4% of trials with delayed responses were excluded with reliable cues. Table 2 shows mean RTs and mean error percentages as a function of cueing condition and S-R correspondence, but collapsed across order of cueing conditions.

RTs. A two-factorial ANOVA was computed on RTs from error-free trials, with cueing and S-R correspondence as within-subjects factors. The main effect of cueing was not significant ($F < 1$). However, the main effect of S-R correspondence was significant, $F(2, 78) = 558.77$, $MSE = 342$, $p < .001$. Spatially corresponding conditions produced shortest RTs (475), spatially neutral conditions produced intermediate RTs (551 ms), and spatially noncorresponding conditions produced longest RTs (567 ms). Finally, the two-way interaction between cueing and S-R correspondence was also significant, $F(2, 78) = 54.01$, $MSE = 329$, $p < .001$. The interaction indicated that cues affected RTs in

Table 2
Reaction Times (RTs) and Percentages of Errors (PEs), Observed in Experiment 2 (N = 40), as a Function of Spatial Stimulus–Response Correspondence and Cue Type

	Cue type							
	Unspecific cue				Reliable cue			
	RT		PE		RT		PE	
Stimulus–response correspondence	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Corresponding	491	52	1.0	1.7	459	58	0.6	1.2
Spatially neutral	543	55	3.8	3.0	558	61	4.1	3.8
Noncorresponding	555	58	8.0	5.2	578	55	8.	6.0
Benefit	52 (2.53)		2.8 (0.96)		99 (3.34)		3.5 (1.00)	
Cost	12 (0.69)		4.2 (0.81)		20 (0.79)		4.3 (0.81)	

Note. Also shown are benefits (neutral − corresponding conditions) and costs (noncorresponding − neutral conditions) in RTs and PEs. The values in parentheses are Cohen's *d*s, a measure of effect size. All benefits and costs are significant on an alpha level of $p < .001$.

the three correspondence conditions differently. RTs in corresponding conditions were faster with reliable cues than with unspecific cues, $t(39) = 6.02$, $p < .001$, $d = 0.95$. By contrast, RTs in neutral conditions and in noncorresponding conditions were slower with reliable cues than with unspecific cues: $t(39) = 3.60$, $p < .01$, $d = 0.57$, for neutral conditions, and $t(39) = 5.33$, $p < .01$, $d = 0.84$, for noncorresponding conditions.

Cost–benefit analysis of RTs. RT benefits from corresponding conditions (neutral minus corresponding RTs) were larger with reliable cues (difference = 99) than with unspecific cues (difference = 52), $t(39) = 7.98$, $p < .001$, $d = 1.26$. In contrast, RT costs from noncorresponding conditions (noncorresponding minus neutral RTs) did not differ between the cueing conditions (Ds = 12 ms and 20 ms), $t(39) = 1.64$, $p = .11$, $d = 0.26$. Overall Simon effects (noncorresponding minus corresponding RTs) were larger with reliable cues (difference = 119 ms) than with unspecific cues (difference = 64 ms), $t(39) = 8.47$, $p < .001$, $d = 1.34$.

Errors. A two-factorial ANOVA was also performed on error percentages. The main effect of cueing was not significant ($F < 1$). The main effect of S-R correspondence was significant, $F(2, 78) = 79.35$, $MSE = 14$, $p < .001$, indicating a Simon effect in errors. The two-way interaction was not significant ($F < 1$).

Discussion

The results of Experiment 2 suggest that cues predicting S-R correspondence in a three-choice task can be used to respond on the basis of stimulus location instead of color, but they cannot be used to adjust the relative weights of different S-R channels. In particular, cues predicting corresponding conditions decreased RTs and increased RT benefits in this condition. By contrast, cues predicting noncorresponding conditions increased RTs in that condition. Moreover, interference from noncorresponding conditions (i.e., performance costs) was similar with reliable and with unspecific cues because reliable cues both increased RTs in neutral and in noncorresponding conditions.

The pattern of results from Experiments 1 and 2 bears some resemblance to the results of a study by Logan, Zbrodoff, and Williamson (1984). These authors investigated how participants exploit the correlation between the relevant colors and the irrelevant meanings of color words in the Stroop task. When there were only two colors and responses in the task, Logan and colleagues observed that the Stroop effect (i.e., the difference between congruent and incongruent conditions) was much larger with a high proportion of congruent trials (i.e., a positive correlation between word color and word meaning) than with a low proportion of congruent trials (i.e., a negative correlation between word color and word meaning). Similar results were obtained by Gratton et al. (1992) in a two-choice Eriksen task and by Hommel (1994) in a two-choice Simon task. By contrast, when Logan et al. used a Stroop task with four responses (and colors), Stroop effects were equivalent with high and low proportions of congruent conditions. Logan et al. explained these findings by assuming that participants used the contingencies between the irrelevant word meaning and the correct response, but could not keep more than two contingencies in mind. A somewhat different explanation of these results would be that participants responded to word color with a high proportion of congruent trials in each task. By contrast, participants might have adopted the strategy of responding incompatible to word meaning with a low proportion of congruent conditions (i.e., a high proportion of incongruent conditions), which is only possible in a two-choice task. This strategy might have reduced interference in incongruent conditions of the two-choice tasks because responding incompatible to word meaning might be faster than naming the color of an incongruent color word.

Our preliminary conclusion from the results of Experiments 1 and 2 is that cues predicting S-R correspondence can be used to switch between stimulus dimensions, but not for changing the relative weights of stimulus dimensions. Before this conclusion can be accepted, however, Experiment 3 investigates whether cueing of spatial S-R correspondence, or cueing of stimulus locations, was responsible for the observed cueing effects in Experiments 1 and 2.

Experiment 3

Experiments 1 and 2 showed that cues informing participants about the different levels of S-R correspondence in an upcoming Simon trial affected performance. A potential problem for the interpretation of this finding is that reliable cues conveyed two different pieces of information to the participants. In particular, the cues informed participants about the level of S-R correspondence in the next trial, and the cues also constrained the set of stimulus locations to the horizontal axis (when corresponding or noncorresponding conditions were cued), or to the vertical axis (when neutral conditions were cued). Thus, it is possible that the effects of the reliable cues, which were observed in Experiments 1 and 2, resulted from participants' attempts to use the cues for directing attention toward a spatial dimension rather than from their attempts to use the cues for preparing themselves for a particular level of S-R correspondence. Experiment 3, therefore, compared the effects of precueing spatial S-R correspondence to the effects of precueing the spatial dimension on which the imperative stimulus would appear in the next display. If cueing effects in the previous experiments resulted from directing attention to a row of stimulus locations, then precueing a spatial stimulus dimension should have the same effect as precuing the level of S-R correspondence.

Experiment 3 also investigated whether giving participants more time for processing the cues would affect their ability to use the cues. In particular, the failure to observe an effect of precueing spatially noncorresponding conditions in Experiment 2 might have resulted from the possibility that the cue–stimulus SOA of 1,200 ms was too short to effectively prepare for a spatially noncorresponding condition in a three-choice Simon task. To address this possibility, we increased the cue–stimulus SOA in Experiment 3 to 2,500 ms.

Method

Participants. Thirty-two new volunteers (students from Universität Halle/Saale: 22 women, 10 men) with a mean age of 24 years (range = 19–40 years) participated for payment (5€) or course credit.

Apparatus and stimuli. The same apparatus and stimuli as in Experiment 2 were used in Experiment 3. In addition to the four cue words that were already used in the preceding experiments, the two German words *waagrecht* (*horizontal*) and *senkrecht* (*verti-*

cal) were used in Experiment 3 to inform participants about the spatial dimension on which the stimulus would appear in the next trial. In particular, the cue *waagrecht* told participants that the stimulus would appear either on the left, central, or the right location (with equal probability), and the cue *senkrecht* told participants that the stimulus would appear either above or below fixation (with equal probability). In the following, we will refer to these cues as the *dimension* cues.

Procedure. Experiment 3 replicated Experiment 2, and additionally investigated the effects of reliable cues about stimulus locations on the pattern of Simon effects. In particular, in Experiment 3, participants performed the Simon task with unspecific cues in five experimental blocks of 36 trials, they performed the Simon task with cues informing them about S-R correspondence in another five experimental blocks of 36 trials, and participants performed the Simon task with dimension cues in another five experimental blocks (of 36 trials). There were two additional warm-up trials in each experimental block that were not recorded. Participants had a practice block of 36 trials before the experimental blocks in each of the three cueing conditions (none, S-R correspondence cues, dimension cues). The order of the three cueing conditions was counterbalanced across participants (i.e., there were five or six participants for each of the six possible orders). A final change concerned the timing of events within the experimental trials. We increased the SOA between the onset of the cue and the onset of the imperative stimulus to 2,500 ms, compared to 1,200 ms in the preceding experiments. This was achieved by presenting the cue for 1,000 ms, followed by a blank period of 500 ms, followed by presenting the five placeholder boxes for 1,000 ms, before adding the imperative stimulus to the display.

Design. Experiment 2 rested on a 3 (S-R correspondence) × 3 (cueing) within-subjects design. Each experimental block contained the same number of spatially corresponding, spatially neutral, and spatially noncorresponding conditions. This was achieved by presenting each corresponding display twice as often as each neutral and each spatially noncorresponding display.

Results

Averaged across participants, 0.4% of trials with premature responses and 4.4% of trials with delayed responses were excluded with unspecific cues, 0.4% of trials with premature responses and 3.8% of trials with delayed responses were excluded with S-R correspondence cues, 0.6% of trials with premature responses and 4.1% of trials with delayed responses were excluded with dimension cues. The results of 1 participant were excluded because his RT (M = 675 ms) exceeded the sample mean (M = 541 ms) by more than two standard deviations (SD = 55 ms). Table 3 shows mean RTs and mean error percentages as a function of cueing condition and S-R correspondence, but collapsed across order of cueing conditions.

RTs. A two-factorial ANOVA was computed on RTs from error-free trials, with cueing and S-R correspondence as within-subjects factors. The main effect of cueing was not significant ($F < 1$). However, the main effect of S-R correspondence was significant, $F(2, 62) = 269.85$, $MSE = 651$, $p < .001$. Spatially corresponding conditions produced shortest RTs (491 ms), spatially neutral conditions produced intermediate RTs (555 ms), and spatially noncorresponding conditions produced longest RTs (572 ms). Finally, the two-way interaction between cueing and S-R correspondence was also significant, $F(4, 124) = 14.31$, $MSE = 362$, $p < .001$.

To uncover the source of the interaction, we analyzed the effect of cueing for each level of the factor S-R correspondence in separate one-factorial ANOVAs. The cueing effect was significant for RTs in corresponding conditions, $F(2, 62) = 5.26$, $MSE = 1{,}295$, $p < .01$. In particular, RTs with S-R correspondence cues were somewhat faster than RTs without cues, $t(31) = 1.58$, $p = .06$ (one-tailed), $d = 0.28$, and significantly faster than RTs with dimension cues, $t(31) = 3.07$, $p < .01$, $d = 0.55$. RTs without cues were somewhat faster than RTs with dimension cues, $t(31) = 1.96$, $p = .06$, $d = 0.35$. The cueing effect was not significant for RTs in neutral conditions, $F(2, 62) = 1.89$, $MSE = 773$, $p = .16$, but was significant for RTs in noncorresponding conditions, $F(2, 62) = 7.99$, $MSE = 489$, $p < .01$. In the latter case, RTs with S-R correspondence cues were slower than RTs without cues, $t(31) = 4.19$, $p < .001$, $d = 0.75$, and slower than RTs with dimension cues, $t(31) = 2.35$, $p < .05$, $d = 0.42$. RTs were not different without cues and with dimension cues, $t(31) = 1.54$, $p = .13$, $d = 0.28$.

Cost–benefit analysis of RTs. Cueing had a significant main effect on benefits (neutral minus corresponding RTs) from corre-

Table 3
Reaction Times (RTs) and Percentages of Errors (PEs), Observed in Experiment 3 (N = 32), as a Function of Spatial Stimulus–Response Correspondence and Cue Type

	Cue type											
	No cue				Correspondence cue				Dimension cue			
	RT		PE		RT		PE		RT		PE	
Stimulus–response correspondence	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Corresponding	493	56	1.3	2.0	476	66	1.1	1.5	505	57	1.7	2.5
Spatially neutral	549	58	4.0	3.9	563	56	4.7	5.4	554	61	5.4	5.7
Noncorresponding	562	56	9.4	7.6	584	53	10.7	6.5	571	55	10.8	9.0
Benefit	56 (2.02)		2.7 (0.81)		87 (2.13)		3.6 (0.78)		49 (1.85)		3.7 (0.82)	
Cost	13 (0.97)		5.4 (0.90)		21 (0.89)		6.0 (1.29)		17 (0.82)		5.4 (0.91)	

Note. Also shown are benefits (neutral − corresponding conditions) and costs (noncorresponding − neutral conditions) in RTs and PEs. The values in parentheses are Cohen's *d*s, a measure of effect size. All benefits and costs are significant on an alpha level of $p < .001$.

sponding conditions, $F(2, 62) = 15.58$, $MSE = 827$, $p < .001$. In particular, S-R correspondence cues produced larger benefits than the condition without cues (difference = 87 vs. difference = 57 ms), $t(31) = 3.79$, $p < .01$, $d = 0.68$, and the condition with dimension cues (difference = 49 ms), $t(31) = 4.62$, $p < .001$, $d = 0.83$. By contrast, benefits without cues were not different from benefits with dimension cues, $t(31) = 1.60$, $p = .12$, $d = 0.29$. Cueing had no significant effect on costs from noncorresponding conditions (noncorresponding minus neutral RTs), $F(2, 62) = 1.52$, $MSE = 403$, $p = .23$.

Errors. A two-factorial ANOVA was also performed on error percentages. The main effect of cueing was marginally significant, $F(2, 62) = 2.54$, $MSE = 11$, $p = .09$. This result reflected a trend for somewhat more errors with cues (S-R correspondence cues: 5.5%, dimension cues: 6.0%) than without cues (4.9%). The main effect of S-R correspondence was significant, $F(2, 62) = 56.12$, $MSE = 35$, $p < .001$, indicating a Simon effect in errors (corresponding: 1.4%, neutral: 4.7%, noncorresponding: 10.3%). The two-way interaction was not significant ($F < 1$).

Comparison between Experiments 2 and 3. To assess whether increasing the cue–stimulus SOA from 1,200 ms (Experiment 2) to 2,500 ms (Experiment 3) affected performance, we directly compared the results from Experiments 2 and 3. A three-factorial ANOVA (Experiment × Cueing × S-R Correspondence) for mixed designs revealed no significant effect of the factor experiment on RTs. Most importantly, the crucial three-way interaction was not significant, $F(2, 140) = 2.21$, $p = .12$ ($F < 1$, for all other tests involving the factor experiment). Similarly, a three-factorial ANOVA showed no effects of the factor experiment on error rates (all Fs < 1.5, all ps $> .20$).

Discussion

Experiment 3 demonstrated that the cueing effects observed in Experiment 2 were neither affected by limited preparation time nor by spatial-cueing effects. In particular, with regard to preparation time, Experiment 3 investigated whether the failure to observe effective preparation for a spatially noncorresponding condition in Experiment 2 resulted from the cue–stimulus SOA of 1,200 ms being too short to allow full preparation. The results of the two experiments were statistically equivalent, suggesting that the inability to prepare for spatially noncorresponding conditions in Experiment 2 (and 3) is not related to limited preparation time.

Experiment 3 investigated a second problem for the interpretation of cueing effects in the present study, namely the effects of information about stimulus location delivered by the reliable S-R correspondence cues. In particular, reliable S-R correspondence cues not only informed participants about the level of S-R correspondence in the next trial, but also about whether the stimulus would appear on the horizontal or on the vertical axis. To disentangle these effects, in Experiment 3 we directly compared the effects of correspondence cueing to the effects of location (i.e., dimension) cueing. The effects of dimension cues were indistinguishable from performance with unspecific cues. Thus, the results of Experiment 3 suggest that participants used the S-R correspondence cues for preparing themselves for the expected level of S-R correspondence, at least when expecting a spatially corresponding condition. By contrast, participants apparently did not prepare for the upcoming spatial stimulus dimension.

The finding that cueing stimulus location has negligible effects on performance in Simon tasks is not unusual. Several studies investigated the effects of precueing the particular spatial location of the imperative stimulus with high validity in two-choice Simon tasks. The typical pattern of results is that valid cues neither facilitate performance compared to conditions without cues nor do they affect the size of the Simon effect (e.g., Proctor, Lu, & Van Zandt, 1992, Experiment 3; Zimba & Brito, 1995). So, if precueing the particular location has negligible effect in Simon tasks, it is not surprising that precueing a set of locations is even less effective.

In summary, the results of Experiments 1–3 demonstrate that participants effectively prepare for spatially corresponding conditions in two-choice and three-choice tasks, whereas participants effectively prepare for a spatially noncorresponding condition only in two-choice tasks.

Experiment 4

The results of Experiments 2 and 3 suggest that participants switch attention to irrelevant stimulus location when expecting S-R correspondence, but are unable to alter the attentional weights of processing channels for color and location when expecting S-R noncorrespondence. However, it is possible that participants are able to decrease the attentional weights for stimulus-location processing, if the task provides no incentives for attending to stimulus location. Specifically, frequently attending to stimulus location in the Simon task might prevent participants from effectively ignoring stimulus location when the cue happens to predict a spatially noncorresponding condition (i.e., response conflict). Hence it is possible that participants may be able to effectively ignore stimulus location in spatially noncorresponding trials if these trials are not intermixed with spatially corresponding conditions. This notion was tested in Experiment 4, where we employed only neutral and noncorresponding conditions and thus removed corresponding conditions entirely. Attending to stimulus location would be useless under these conditions, and thus the alternative strategy of gating might now show up. This would be indicated by reduced costs from expected compared to unexpected S-R noncorrespondence.

Method

Participants. Twenty-eight new volunteers (students from Universität Erlangen: 18 women, 10 men) with a mean age of 22 years (range = 19–35 years) participated for payment (5€) or course credit.

Apparatus and stimuli. The apparatus and stimuli from Experiment 2 were also used in Experiment 4, except for the fact that only three cue words were used (attention, neutral, incompatible).

Procedure. The procedure of Experiment 4 was the same as in Experiment 2. Half of the participants performed the Simon task with unspecific cues first, whereas the other half did the Simon task with reliable cues first. The first group of participants practiced the Simon task with unspecific cues in Block 1, then performed four experimental blocks with unspecific cues, then practiced the Simon task with reliable cues in Block 6, and finally did four experimental blocks with reliable cues. The second group practiced the Simon task with unspecific cues in Block 1, then practiced the Simon task with reliable cues in Block 2, then performed four experimental blocks with reliable cues, and finally did four experimental blocks with unspecific cues. Each block contained 36 experimental trials plus two warm-up trials (which were not analyzed).

Design. Experiment 4 rested on a 2 (S-R correspondence) × 2 (cueing) within-subjects design. Each experimental block contained the same number of spatially neutral and spatially noncorresponding conditions.

Results

Averaged across participants, 0.5% of trials with premature responses and 4.2% of trials with delayed responses were excluded with unspecific cues; 0.7% of trials with premature responses and 4.2% of trials with delayed responses were excluded with reliable cues. Table 4 shows mean RTs and mean error percentages as a function of cueing condition and S-R correspondence, but collapsed across order of cueing conditions.

RTs. RTs from error-free trials were subjected to a two-factorial ANOVA, with cueing and S-R correspondence as within-subjects factors. The main effect of cueing was significant, $F(1, 27) = 13.02$, $MSE = 417$, $p < .01$, indicating shorter RTs with unspecific cues than with reliable cues (537 vs. 551 ms). Moreover, the main effect of S-R correspondence was significant, $F(1, 27) = 10.89$, $MSE = 146$, $p < .01$, reflecting shorter RTs in neutral conditions (540 ms) than in noncorresponding conditions (548 ms). The two-way interaction was not significant ($F < 1$).

Analysis of costs in RTs. There was significant interference from noncorresponding conditions (i.e., an RT cost) with unspecific cues (533 vs. 541 ms), $t(27) = 2.38$, $p < .05$, $d = 0.45$, and with reliable cues (547 vs. 555 ms), $t(27) = 2.33$, $p < .05$, $d = 0.44$. Thus, RT costs were equivalent to the millisecond with cued and uncued S-R correspondence.

Errors. A two-factorial ANOVA was computed on error percentages. The main effect of cueing was not significant ($F < 1$). However, the main effect of S-R correspondence was significant, $F(1, 27) = 17.68$, $MSE = 7.72$, $p < .001$, indicating Simon interference in errors (5.1% vs. 7.3%). The two-way interaction was not significant ($F < 1$).

Discussion

The results of Experiment 4 replicated the results of Experiment 2 and 3 by demonstrating equivalent interference from irrelevant stimulus location with S-R correspondence cues and without cues in a three-choice task. This was the case regardless of whether the task contained corresponding conditions (Experiment 2) or not (Experiment 4). This further supports the conclusion that participants are not able to use cues predicting noncorresponding S-R events for gating location processing in a Simon task.

General Discussion

The present study investigated the ability to prepare for a situation in which a visual stimulus affords spatially corresponding or spatially noncorresponding responses to a nonspatial stimulus feature. Basically, two ways of preparation are conceivable. The first way of preparing for S-R correspondence entails switching attention from the nominally relevant stimulus dimension (e.g., color) to the nominally irrelevant stimulus dimension (i.e., location), and to infer the correct response from the irrelevant attribute (e.g., Logan & Zbrodoff, 1982). Attention switching can be used if the participant knows the relationship between the irrelevant stimulus attribute and the required response in advance. This is the case in corresponding conditions and in noncorresponding conditions of two-choice tasks, but not in noncorresponding conditions with more than two possible responses. The second way of preparing for S-R correspondence—gating—entails adjustments of the relative weights of parallel S-R channels (Botvinick et al., 2004; Stürmer et al., 2002). In particular, participants may increase the attentional weight for processing of stimulus location when expecting a spatially corresponding situation. Moreover, participants may increase the attentional weight for processing of stimulus color and/or decrease the attentional weight for stimulus location when expecting a spatially noncorresponding situation. In contrast to attention switching, gating is, in principle, always applicable.

We conducted four experiments, in which we investigated the effects of precueing spatial S-R correspondence on benefits from spatially corresponding conditions and on costs from spatially noncorresponding conditions in Simon tasks with two or three

Table 4
Reaction Times (RTs) and Percentages of Errors (PEs), Observed in Experiment 4 (N = 28), as a Function of Spatial Stimulus–Response Correspondence and Cue Type

	Cue type							
	Unspecific cue				Reliable cue			
	RT		PE		RT		PE	
Stimulus–response correspondence	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Spatially neutral	533	42	4.9	5.0	547	49	5.4	5.1
Noncorresponding	541	44	7.3	6.2	555	48	7.3	5.8
Cost	8 (0.45)		2.4 (0.67)		8 (0.44)		2.0 (0.50)	

Note. Also shown are benefits (neutral − corresponding conditions) and costs (noncorresponding − neutral conditions) in RTs and PEs. The values in parentheses are Cohen's *d*s, a measure of effect size. All costs are significant on an alpha level of $p < .05$.

possible responses. The results of the experiments can be summarized as follows. Precueing spatial S-R correspondence improved performance in corresponding and in noncorresponding conditions of a two-choice task (Experiment 1). By contrast, precueing spatial S-R correspondence only improved performance in corresponding conditions, but not in noncorresponding conditions of three-choice tasks (Experiments 2–4). In summary, the pattern of results is consistent with the notion that participants can use S-R correspondence cues to switch between responding on the basis of stimulus color and responding on the basis of stimulus location (attention switching). However, it appears that participants cannot gradually amplify or suppress the processing of stimulus location while being set to process stimulus color (gating).

Before discussing further implications of our results, it is necessary to address two methodological problems of the present experiments. First, S-R correspondence cues not only allowed preparation for the level of S-R correspondence in the next trial, but also allowed to direct spatial attention to the horizontal or vertical row of stimulus locations in our displays. Experiment 3 directly addressed this issue. Here we found that S-R correspondence cues affected performance whereas spatial-dimension cues did not. This finding clearly demonstrates that participants used the S-R correspondence cues to prepare for the level of S-R correspondence, and not for directing attention toward a particular spatial dimension. Moreover, the uselessness of dimension cues suggests that the task as such afforded little attentional orienting toward the horizontal or vertical row of stimulus locations.

Second, every analysis of costs and benefits in performance requires the availability of an appropriate neutral condition. It is relatively easy to define a spatially neutral condition in a two-choice Simon task (e.g., Experiment 1). In this case, presenting stimuli at locations that vary on the vertical meridian represents a widely accepted neutral condition (cf. Zorzi & Umiltà, 1995; but see Simon & Acosta, 1982). By contrast, it is much more difficult to find a spatially neutral condition in a three-choice Simon task. Consider the three-choice tasks used in Experiments 2 and 3. In these cases, participants responded at three locations on the horizontal axis (i.e., there was a left, a central, and a right response location). Stimuli appeared at five locations that varied on the horizontal and on the vertical axis (i.e., left, above, right, below, central). Stimuli appearing above and below fixation were defined as neutral conditions in Experiments 2–4 because there was neither an "above" nor a "below" response in the response set. But because the neutral stimulus locations were located centrally, and there was a central response location as well, one might argue that the neutral stimulus locations were in fact compatible to the central response location, but incompatible to the left and right response locations. From this point of view, the neutral conditions in Experiments 2–4 actually constituted a mixture of corresponding and noncorresponding conditions. To test this interpretation, we conducted post hoc analyses in which we compared RTs in neutral conditions with responses at the central location (corresponding neutral condition) to RTs in neutral conditions with responses at peripheral locations (noncorresponding neutral condition). For Experiment 2, results showed faster RTs in corresponding neutral conditions than in noncorresponding neutral conditions with unspecific cues (532 vs. 549 ms), $t(39) = 3.01$, $p < .01$, $d = 0.50$, but not with reliable cues (555 vs. 562 ms), $t(39) = 1.06$, $p = .30$, $d = 0.20$. For Experiment 4, RTs in corresponding neutral conditions were always equivalent to RTs in noncorresponding neutral conditions: for unspecific cues, 532 vs. 534 ms, $t(27) = 0.33$, $p = .75$, $d = 0.10$; for reliable cues: 550 vs. 547 ms, $t(27) = 0.42$, $p = .68$, $d = 0.10$. These results demonstrate that the neutral conditions in Experiments 2 and 4 were neutral in most of the cases. Moreover, any difficulties to interpret the results in the neutral conditions would not affect the interpretation of cueing effects on absolute RTs in corresponding or noncorresponding conditions, which were generally consistent with the results of the cost–benefit analyses.

The results of the present study suggest that attention switching is available as a means for the regulation of expected response conflict in the Simon task. Attention switching involves responding to nominally irrelevant stimulus location if location specifies the correct response reliably. This strategy regulates response conflict in the Simon task because responding to irrelevant stimulus location decreases interference from the nominally relevant, but unattended, stimulus color. This is because, in the Simon task, there are stronger S-R associations between stimulus location and response location than between stimulus color and response location. Hence, responding to irrelevant stimulus location exploits these stronger S-R associations for improving performance and, at the same time, decreases interference from the unattended stimulus dimension.

The results of the present study also suggest that gating is unavailable as a means for the regulation of expected response conflict in the Simon task. In particular, participants seem unable to gradually increase or decrease attention to stimulus location in the Simon task, while simultaneously processing stimulus color. Otherwise, participants should have been able to use cues predicting noncorresponding conditions for decreasing the impact of noncorresponding stimulus locations on performance irrespective of the number of possible responses. This was not the case, however. Thus, participants appear to have little control over the strength of perceptual processing of stimulus location while they are processing a nonspatial stimulus feature.

Although gating turned out to be inefficient in the present Simon-like paradigm, it appears to be a powerful explanatory concept in other sorts of perceptual selection tasks. For example, Müller and colleagues proposed that visual search involves a process that increases the attentional weight for the processing module of the relevant feature dimension, compared to the processing modules for irrelevant feature dimensions (e.g., Found & Müller, 1996; Müller, Heller, & Ziegler, 1995; Müller, Reimann, & Krummenacher, 2003). In a recent study, Müller et al. (2003) demonstrated that participants can adjust the attentional weights for perceptual dimensions (i.e., color vs. orientation) on the basis of symbolic cues. Participants searched for an odd-one-out target in a cross-dimensional search task, in which the target could differ from distracters on one of two different perceptual dimensions (color vs. orientation). Müller et al. showed that precueing the critical feature dimension revealed faster detection times for an odd-one-out target, compared to a condition without precueing, even when the particular feature value changed between trials. This result suggests that participants can increase the attentional weight for a relevant perceptual dimension and/or decrease the attentional weight for an irrelevant perceptual dimension on the basis of advance information. It is important to note, however, that the studies by Müller and colleagues leave open the question of whether dimensional weights are assigned in an all-or-none fashion, or in a graded fashion.

Given the basic demonstration of attentional weighting in visual-search tasks, future research might demonstrate that gating provides a means for the regulation of expected response conflict in other conflict tasks. It may be possible, for example, that gating of shape information is possible in congruent and incongruent conditions of a Stroop task, when participants are instructed to process stimulus color and to ignore word shape. This is a matter for future research.

An interesting implication of the present findings is that attention switching may also play a role in reactive regulation of response conflict in Simon tasks. In particular, it is possible that a corresponding condition in a Simon trial induces a bias to respond compatible to stimulus location in the next trial, whereas a noncorresponding condition may induce a bias to respond incompatible to stimulus location in the next trial. Obviously, a bias to respond compatible to stimulus location may improve performance if a corresponding trial follows a corresponding trial, whereas such a bias would impair performance if a noncorresponding trial follows a corresponding trial. Similarly, a bias to respond incompatible to stimulus location may improve performance if a noncorresponding trial follows a noncorresponding trial in a two-choice task, but not in a three-choice task. Unfortunately, no study is available in which sequential effects on costs and benefits were examined in Simon tasks with two and more response alternatives. We have already begun to investigate this issue.

In summary, the present study demonstrates a limit in the ability to prepare for response conflict in the Simon task. It is interesting to note that Kleinsorge (2007) recently demonstrated a similar limit in the ability to prepare for interference from processing the irrelevant emotional content of visual stimuli. Thus, it seems that preparation for stimulus or response conflict is a difficult task, and every demonstration of how to overcome this difficulty is welcome both for theoretical as well as for practical reasons.

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