

Asymmetries in a Unilateral Flanker Task Depend on the Direction of the Response: The Role of Attentional Shift and Perceptual Grouping

Jörn Diedrichsen and Richard B. Ivry
University of California, Berkeley

Asher Cohen
Hebrew University

Shai Danziger
University of Wales, Bangor

Four experiments were conducted using a flanker task with 1 distractor appearing either on the left or right side of a central target. Responses were made on a keyboard aligned parallel to the displays. A larger flanker effect was obtained when the distractor was on the same side as the response. Two factors account for this asymmetry. First, when the flanker and target are identical, the 2 form a group that is assigned a spatial tag, creating a form of the Simon effect on the basis of the compatibility between the response keys and the group. Second, preparation of a lateralized response appears to entail a shift of visual attention in the corresponding direction, thus enhancing processing of the flanker on the response side. Consistent with the 2nd hypothesis, participants were more likely to correctly recognize letters that were briefly presented at the distractor position on the same side as the response.

Visual attention has been studied in a variety of tasks in which participants are required to respond to a target at a known location while attempting to ignore irrelevant information presented at distractor locations. One widely used task is the flanker task, first introduced by B. A. Eriksen and Eriksen (1974). In this task, a target stimulus is presented at the center of a display, and participants make a speeded identification response. For example, if the target dimension is color, one response is made if the target is green, and a different response is made if the target is red. The target is flanked by distractor stimuli that are mapped to the same responses (i.e., red or green) or are neutral in terms of their response assignment (i.e., blue). The flanker effect refers to the fact that participants are faster to respond and make fewer errors when the target and distractors are congruent (i.e., red target flanked by red distractors) compared with when the target and distractors are incongruent (i.e., red target flanked by green distractors). Response latencies in the neutral condition, in which the flankers are not associated with assigned responses (i.e., red target flanked by blue distractors), are typically intermediate, indicating that the

flanker effect entails both facilitation and interference (e.g., Cohen & Shoup, 1997).

The very existence of the flanker effect reveals limitations in the focused allocation of visual attention. Although the target always appears at a known, central location, people are unable to ignore the peripheral distractors. The locus of this interference remains controversial. Some theorists have attributed flanker interference to competitive processes occurring at the level of stimulus identification (Kornblum, Hasbroucq, & Osman, 1990). On the other hand, considerable evidence suggests that a prominent source of interference arises at stages of processing associated with response selection (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; C. W. Eriksen & Eriksen, 1979; see Cohen & Shoup, 1997, for a review). That is, because of limitations in selective attention, task-relevant responses associated with the target and distractors are both activated, and it is primarily the interaction of these codes that underlies the flanker effect.

In the standard version of the flanker task, the central target is flanked by two identical distractors. Several investigators have modified this display arrangement to examine asymmetries that might arise as a function of the position of the distractors. In these studies, a task-relevant distractor is presented on only one side, or distractors are presented on both sides but are different from each other, so that the influence of each distractor can be determined. We call these designs unilateral and mixed flanker displays, respectively.

One such study was reported by Harms and Bundesen (1983). They found that for letters the flanker effect was larger when a distractor letter was presented on the left side of the target compared with when the distractor was presented on the right side. They interpreted this asymmetry as reflecting hemispheric asymmetries, with the right cerebral hemisphere presumed to be faster in identifying single letters than the left hemisphere. However, Hommel (1995)

Jörn Diedrichsen and Richard B. Ivry, Department of Psychology, University of California, Berkeley; Asher Cohen, Department of Psychology, Hebrew University, Jerusalem, Israel; Shai Danziger, School of Psychology, University of Wales, Bangor, United Kingdom.

This work was supported by National Institutes of Health Grants RO1MH51400 and P01NS2778.

We wish to thank Thomas R. Richardson and Kristi Hiatt for collecting data and Jon Driver, Bernhard Hommel, Claus Bundesen, and Steffen Werner for helpful comments.

Correspondence concerning this article should be addressed to Jörn Diedrichsen or Richard B. Ivry, Department of Psychology, University of California, Berkeley, California 94720. Electronic mail may be sent to jdiedri@socrates.berkeley.edu or to ivry@socrates.berkeley.edu.

argued that the asymmetry was due to a left-to-right scanning process for verbal material. By this hypothesis, the flanker and target are assumed to resemble words and thus to trigger the scanning process leading to a bias in processing of the left-sided flanker. In support of this account, Hommel found that the asymmetry disappeared when the spacing between letters was increased, rendering them less wordlike. Moreover, for mirror-reversed letters, the asymmetry reversed, with the letter on the right producing a larger effect, although this interaction was only marginally significant. Thus, the left-right asymmetry appears to be limited to wordlike stimuli.

More recently, unilateral flanker displays have been used to study the performance of patients with focal brain lesions. Cohen, Ivry, Rafal, and Kohn (1995) tested two patients with extinction, a disorder of attention in which the patients show markedly reduced awareness of stimuli presented in the contralesional hemifield. Despite this deficit, extensive implicit processing of the neglected information has been observed in studies using indirect measures such as priming (see McGlinchey-Berroth, Milberg, Verfaellie, Alexander, & Kilduff, 1993). Cohen et al. provided further evidence of this phenomenon, showing that the magnitude of the flanker effect was similar when the single distractor was presented in the contralesional hemifield compared with when it was presented in the ipsilesional hemifield. Thus, response code activation does not require that participants be aware of the irrelevant information.

Rafal et al. (1996) followed up on this result, testing patients with lesions in either the left or right lateral prefrontal cortex, a cortical region that has been associated with the preparation, maintenance, and selection of task-relevant responses (e.g., Frith, in press). For these patients, the flanker effect was much larger when a unilateral flanker was presented in the ipsilesional hemifield. This asymmetry was obtained even though the patients were fully aware of the flankers on either side, and in fact, patients showed no asymmetry in response latencies when required to report the identity of the flankers. Thus, Rafal et al. concluded that the lateral prefrontal cortex is critical for maintaining the codes linking stimuli to particular responses and that the activation of these codes is lateralized, with each hemisphere biased to represent potential actions associated with stimuli in the contralateral hemifield.

The current project was initiated to further test this hypothesis with neurologically healthy individuals. Rafal et al. (1996) proposed that the response codes for lateralized stimuli are primarily represented in the contralateral hemisphere. Assuming that this hemisphere is dominant in the control of the contralateral hand, then the magnitude of the flanker effect should show an interaction between the side of the flanker and the hand used to respond. Specifically, we predicted that when all responses were made with the right hand, the flanker effect would be greater when the distractor was to the right of the target and, correspondingly, that the flanker effect from left-side distractors would be greater when responses were made with the left hand. Consider the former situation. We assume that the left hemisphere is dominant when responding with the right hand. With

distractors on the right, response codes associated with both the central target and distractor items would be activated in the left hemisphere, leading to response competition. However, with left-side distractors, only the response code associated with the target would be strongly activated in the left hemisphere, and thus the flanker effect would be attenuated.

As shown below, the results failed to provide support for this prediction. However, we did obtain an interesting asymmetry between the side of the response and the side of the flanker, with the flanker effect larger when the distractor was on the same side as the response (irrespective of which hand was used to make the response). Subsequent experiments suggest that this asymmetry is due to two factors that affect spatial processing. One factor is perceptual grouping of the target and distractor, which affects the perceived position of the target and leads to a form of the Simon effect, on the basis of compatibility between the response keys and the spatial position of the group. The second, novel factor is a shift of visual attention in the direction of the position of the required response. These results provide further evidence for the spatial and action-based nature of visual attention. We elaborate on these two factors after the presentation of Experiment 1.

Experiment 1

We tested healthy college-age students on a unilateral flanker task. On each trial, the participants made a speeded response, indicating whether a target circle presented at fixation was colored green or red. One distractor circle, colored either green, red, or blue, was presented alongside the target, either on the left or right side. On the other side, an achromatic stimulus was presented to maintain the overall spatial balance of the display because attention has been shown to be directed toward the center of mass of a display (Grabowecky, Robertson, & Treisman, 1993). We used color as the task-relevant dimension to avoid left-right asymmetries associated with processing wordlike stimuli (Harms & Bundesen, 1983; Hommel, 1995). On half of the experimental blocks, the participants had to respond with two fingers of their left hand and on the other half with two fingers of their right hand. As a result of this procedure, we could evaluate whether there was an interaction between the side of the distractor and the hand used to respond.

Method

Participants. Sixteen undergraduate students were recruited from the research participant pool of the Psychology Department at the University of California, Berkeley. All had normal or corrected to normal vision. They all reported having normal color vision and being right-handed.

Apparatus and stimuli. Stimulus presentation and response collection were controlled by a 386-based personal computer. The stimuli were presented on a 14-in. (35.6-cm) VGA monitor (Sony Trinitron) with 640 × 320 pixel resolution. The participants were seated 97 cm from the screen. They rested their heads in a chin rest to maintain this distance. Responses were made on two horizon-

tally aligned Plexiglas keys of a response board, with a 7-mm distance separating the 2-cm keys.

The stimuli were displayed at the center of the monitor. Each stimulus array consisted of three rings (i.e., the letter *O*). The middle ring, the target, subtended a visual angle of 0.35° in width and 0.47° in height. Two rings that were somewhat larger in size, measuring 0.53° in width and 0.7° in height, flanked the target. The edge-to-edge horizontal distance between the target and flanking rings was 0.59° . A white line, 0.53° in length, was drawn under each ring. These lines were included to assist the participants in focusing their attention at the center position, the location of the target on all trials. The target circle was either green or red. One of the flanking rings—the distractor—was green, red, or blue. The other flanking ring was always gray. The colors were highly discriminable, set by using only one of the three color guns of the VGA monitor for the target and distractor and by using an equal balance from all three for the gray ring and lines. The testing chamber was dimly illuminated from a back-projected light bulb placed behind the computer screen.

Procedure. Participants were tested individually. The three lines were visible throughout the test session. Each trial began with the presentation of an asterisk above the middle line of the display. The asterisk served to alert the participants to the upcoming trial and served as a fixation point because the target would appear at the same location. After a 500-ms fixation interval, the asterisk was erased, and the screen remained blank except for the three white lines. After another 500 ms, the three rings appeared. A speeded response was required, with the participant pressing one of the two response keys to indicate whether the center ring was green or red. The participants were instructed to respond as fast as possible, while keeping errors to a minimum. Incorrect responses were followed by the presentation of one 1,000-Hz tone. If no response was detected within 6 s, no response was recorded for that trial, and two 1,000-Hz tones were presented. The intertrial interval was 1.5 s.

There were 12 kinds of trials (2 target colors \times 3 distractor colors \times 2 distractor positions). Within a block, each trial type occurred eight times for a total of 96 trials. Each participant completed six experimental blocks, responding with each hand on three consecutive blocks. The starting hand was counterbalanced across participants. Responses were made with the index and middle finger of the designated hand. Further counterbalancing was performed on the response mapping, with the left–right order being green–red for half of the participants and red–green for the other half. Prior to the first test block with each hand, a practice block consisting of 36 trials was run. The entire experimental session lasted approximately 50 min.

Results

The participants responded correctly on 97% of the trials. Trials on which the response was incorrect were excluded from the response time (RT) analysis, as were correct responses in which the RT was less than 100 ms or greater than 1 s. The RT criterion resulted in the exclusion of an additional 0.6% of the total trials. The data of 1 participant were excluded from further analysis. Even after excluding 5% of his responses because they were longer than 1 s, his mean RT was considerably longer (556 ms) than that obtained for the other participants ($M = 442$ ms, $SD = 37$ ms).

The mean RT for each participant in each condition was computed and submitted to a four-way repeated measure

analysis of variance (ANOVA). The variables of the ANOVA were hand (left or right hand), response side (left or right response key), distractor position (colored distractor was on left or right side of target), and congruency (target–distractor relationship was congruent, incongruent, or neutral). In accord with previous results with this task (Cohen et al., 1995; Rafal et al., 1996), there was a significant congruency effect, $F(2, 28) = 19.04$, $p < .001$. Overall, congruent trials resulted in faster latencies (433 ms) than incongruent trials (450 ms), with the mean latency on neutral trials falling between these two values (441 ms). The difference between congruent and incongruent trials was only 17 ms. This value was similar to that obtained in pilot studies for the Cohen et al. (1995) study. The relatively small magnitude of the effect likely reflects the fact that there was only one task-relevant distractor.

The hypothesis that the magnitude of the flanker effect would be greatest when the distractor appeared on the same side as the responding hand predicts an interaction of three variables: hand, distractor position, and congruency. This three-way interaction was only marginally significant, $F(2, 28) = 2.81$, $p = .077$, although the trend was in the predicted direction. When the distractor was on the same side as the responding hand, the difference between the congruent and incongruent trials was 21 ms. When the distractor was on the opposite side from the responding hand, the difference was only 14 ms. A two-tailed *t* test of these difference scores also failed to reach statistical significance, $t(14) = 1.49$, $p = .15$. Some caution should be taken in interpreting this null result, given that the power is relatively low. Using a criterion power level of .80, a sample size of 95 participants would be required to reach significance, given a mean difference of 7 ms with a standard deviation of 18 ms.

Unexpectedly, there was a significant three-way interaction of response side, distractor position, and congruency, $F(2, 28) = 15.57$, $p < .001$. To make this effect transparent, we recoded the data in terms of a new variable: correspondence. Trials in which the position of the distractor and the correct response key were the same in terms of relative position were labeled *corresponding* (e.g., right-side distractor with green target for a participant for whom the green response key was on the right side of the response board). Trials in which the position of the distractor and the correct response key had different relative positions were labeled *noncorresponding* (e.g., left-side distractor with green target for a participant for whom the green response key was on the right side of the response board). Note that the terms corresponding and noncorresponding do not vary as a function of distractor–target congruency but rather simply refer to the relative spatial positions of the distractor and correct response key. The mean latencies and error rates in terms of the correspondence variable are shown in Figure 1. When the distractor was on the same side as the response, the flanker effect was 29 ms. When the distractor was on the opposite side of the response, the flanker effect was reduced to 6 ms.

The error data were submitted to similar analyses. Rather than use the raw data in the ANOVA, we entered values obtained after an arcsine transformation was performed on

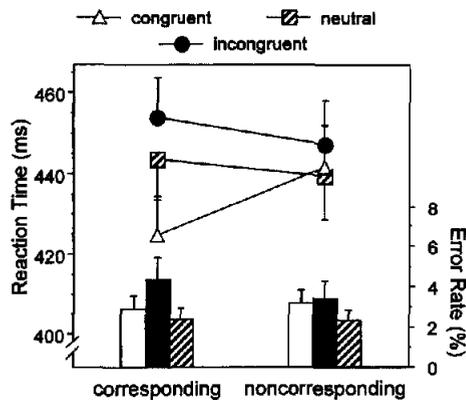


Figure 1. Mean reaction times (lines) and error rates (bars) in Experiment 1 as a function of distractor congruency and correspondence between distractor position and response side. Error bars indicate standard error.

the accuracy scores. This transformation was necessary, given a significant deviation from the normal distribution that was due to the low error rates. Unlike the RT data, there was no main effect of congruency, $F(2, 28) = 2.07, p = .145$. The test for a three-way interaction between hand, distractor position, and congruency was not significant, $F(2, 28) < 1$. In contrast, there was an effect related to the correspondence between the distractor position and response side, as indicated by the significant interaction between response side, distractor position, and congruency, $F(2, 28) = 6.11, p = .006$.

Discussion

Contrary to our expectations, the results do not support the hypothesis that the influence of the distractor would be greater when it was presented on the side of the responding hand. This null result is tempered by the fact that the three-way interaction approached significance in the RT data. Furthermore, it is possible that the distractors were not strictly lateralized for at least two reasons. First, we did not directly monitor eye movements. We assumed that participants fixated at the center position, both because of our task instructions and because the target always appeared at this position. Second, despite the fact that the flanking circles were presented to the left and right of the target, their eccentricity was still quite small, with the center of the distractor about 1° from the center of the display. Receptive fields, even in relatively early visual areas, span the ipsilateral visual field to this distance (e.g., Gattass, Sousa, & Gross, 1988), thus providing some direct input from each flanker to both the contra- and ipsilateral hemispheres. Nonetheless, the displays used in this study are comparable to those in Rafal et al. (1996), and using a higher eccentricity would result in a much weakened influence of the distractors. Moreover, we have conducted a series of other experiments to provide a more rigorous test of the laterality

hypothesis. In none of these has there been a significant interaction between distractor position and response hand.¹

Experiment 1 did reveal a different way in which the magnitude of the flanker effect was modulated. The congruency effect was greater when the relative positions of the target and response key were in correspondence. For example, when the target required a response on the left response key, the congruency effect was larger when the distractor had appeared on the left side. We consider two possible explanations for this finding.

The attentional-shift hypothesis. The congruency effect arises because people are unable to completely filter out the flanking objects. Even though they know they need only respond to the stimulus at the center position, the effect indicates that the distractors are processed to a sufficient degree so as to activate associated response codes. The magnitude of the congruency effect is, however, a function of the distance between the target and distractor (e.g., B. A. Eriksen & Eriksen, 1974). If the flanking items are moved to more eccentric locations, the congruency effect can be eliminated. This attenuation with distance can be interpreted as demonstrating a spatial extent of the focus of attention (cf. Cohen & Shoup, 1997). When this distance is sufficiently great, the target and distractors are sufficiently separated such that responding to the target is no longer influenced by the distractors.

Following this line of reasoning, we propose that the focus of spatial attention is reallocated in the direction of a forthcoming response (see Figure 2, upper panel). As information concerning the identity of the target accumulates, the participant begins to prepare a spatially directed response, pressing the key on either the left or right side of the keyboard. We assume that the effect of this action code is not limited to the motor system. Rather, visual attention is also shifted in the direction of this candidate response. A consequence of this shift is that processing efficiency for the two flanking positions becomes asymmetric, with more efficient processing occurring for the flanking object that is on the same side as the forthcoming response. Note that this hypothesis assumes a high degree of interaction between perceptual- and response-selection processes. Sufficient processing of the target color must have occurred to produce the attentional shift, and this response-based shift must occur

¹ We conducted three other studies to test the laterality hypothesis (Ivry, Cohen, Diedrichsen, & Danziger, 1997). In the first one, we used a mixed flanker task. A congruent or incongruent distractor on one side could be presented together with a congruent, incongruent, or neutral distractor on the other side. In the second and third experiments, the distractor could be presented not only to the left and the right of the target but also above and below it. The keyboard was aligned either in a horizontal or vertical fashion. This arrangement allowed the lateralization of the stimuli and the direction of the response axis to be orthogonal. In none of the studies was there any evidence of an interaction involving the hand used for responding, distractor position, and distractor congruency. However, in all of the studies, the three-way interaction between response side, congruency, and distractor position was significant when the keyboard was parallel with the alignment of the flankers, replicating the unexpected finding of Experiment 1.

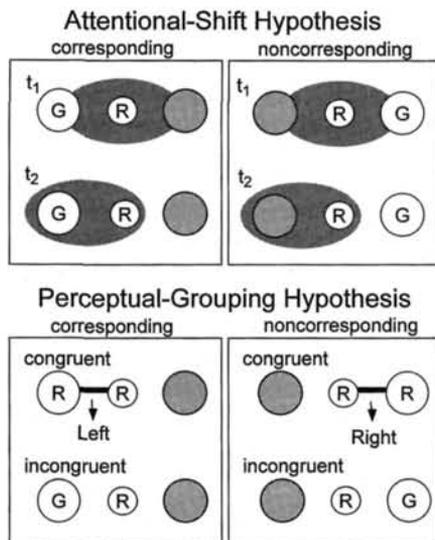


Figure 2. Two hypotheses for the asymmetry in the reaction time data of Experiment 1. The graph shows a situation with a red target (small circle with *R*) and a response mapping red–left key, green–right key. The position of the distractor (large circle with *R* or *G*) is either corresponding (left trials) or noncorresponding (right trials) with the side of the response. The attentional-shift hypothesis (upper panel) predicts for both congruent and incongruent trials that when the display is presented (t_1), visual attention (represented by the gray oval) is focused on the center target. When the appropriate response is prepared (t_2), attention is shifted to the side corresponding with the response and leads to a larger influence of the corresponding distractor. The perceptual-grouping hypothesis (lower panel) proposes that in congruent trials the target and distractor form a perceptual group (indicated by the connecting line), which then induces a task-irrelevant spatial code. This code interferes or facilitates response execution. No grouping occurs on incongruent and neutral trials for which no asymmetry should be observed. *G* = green; *R* = red.

with sufficient rapidity that it allows a distractor on that side to exert a stronger influence on the actual RT compared with the influence of a distractor on the other side. Interactive models of this sort are not compatible with strictly serial models in which perceptual identification proceeds response selection (e.g., Kornblum et al., 1990).

The idea that the focus of attention is intimately linked to action systems has been proposed by a number of researchers (Rizzolatti, Riggio, & Sheliga, 1994; Tipper, Lortie, & Baylis, 1992). According to this view, spatial information is essential for the preparation of potential actions, with separate representations existing for different types of movements (e.g., oculomotor or reaching). Spatial selective attention is embedded in these representations, with the focus of attention intimately linked to the potential actions. The reference frame on which attention operates reflects these links. For example, in reaching for an object, attention may shift from an initial focus at the starting position of the hand to the location corresponding to the goal of the action (Rizzolatti et al., 1994). In support of this hypothesis, Tipper et al. reported that the latency to initiate a reaching

movement increased when distracting stimuli are in the vicinity of the trajectory of the planned movement. By varying the starting position of the hand and direction of the trajectory with respect to the body (i.e., movements either away from or toward the body), attention was found to operate in an action-centered representation.

The perceptual-grouping hypothesis. An alternative explanation of the interaction between the position of the distractor and the relative position of the response can be derived by considering the Simon effect (Simon & Small, 1969; for a review, see Lu & Proctor, 1995). In a Simon task, the relevant stimulus dimension is a nonspatial feature such as shape or color, with the target stimulus being presented on one side or the other of fixation. Responses to different values on this dimension are assigned to spatially coded responses (e.g., left and right response keys). The Simon effect refers to the fact that although stimulus position is irrelevant, this factor interacts with the position (or direction) of the response. Responses are faster when a target's location corresponds to the location of its assigned response than when stimulus–response mappings are spatially incongruent. The effect is explained by the fact that the position of the target automatically invokes a spatial code and that this spatial code interacts with the spatial code associated with the response (e.g., Wallace, 1971), or, more precisely, the location of the consequence of an action (Hommel, 1993a).

In Experiment 1, the target was always presented at the center of the display. However, on congruent trials, the target and distractor were the same color. Thus, they could be seen as forming a perceptual group, shifted to one side of the display (see Figure 2, lower panel). The key idea of the perceptual-grouping hypothesis is that as with the Simon effect, a spatial code is automatically generated, corresponding to the relative position of the group.² For example, if a congruent flanker is to the left of the target, then the spatial code for this group would be “left”. If that target is associated with the left response key, then the two spatial codes are in correspondence with one another. If that target is associated with the right response key, then the two spatial codes are in conflict. Response latencies should be faster in the former situation, analogous to what happens in standard conditions eliciting a Simon effect.

In summary, the attentional-shift and perceptual-grouping hypotheses provide two interpretations of the asymmetric flanker effects observed in Experiment 1. The attentional-shift hypothesis posits that the influence of the distractor varies as a function of its position with respect to the side of the forthcoming response. In contrast, the perceptual-grouping hypothesis assumes that the congruency effects in Experiment 1 are a composite of two factors. First, there is the flanker effect, reflecting the activation of response codes associated with the distractor. On top of this is a Simon-like effect that produces asymmetric effects on congruent trials. The asymmetry from this perspective is a consequence of perceptual grouping.

These two hypotheses are not mutually exclusive, nor do the results of Experiment 1 provide strong evidence in favor

² We are grateful to Jon Driver for suggesting this hypothesis.

of one hypothesis over the other. One difference between the two hypotheses is that the perceptual-grouping hypothesis predicts that the asymmetry should be limited to congruent trials because this is the only condition in which perceptual grouping should occur. To test this prediction, we directly compared trials from Experiment 1 with the distractor on the corresponding and noncorresponding side. In accord with the grouping hypothesis, responses on congruent trials were 17 ms faster when the congruent distractor was on the same side as the response compared with when the distractor and response were on opposite sides, $t(14) = 5.17, p < .001$. However, for incongruent trials, RTs were 7 ms slower when the distractor was on the same side as the response, a difference that approached significance, $t(14) = 2.01, p = .054$.³ Asymmetries on incongruent trials cannot be explained by the grouping hypothesis, assuming that a group would not be formed when the target and distractor are different colors.

A second prediction of the perceptual-grouping hypothesis can also be evaluated with the congruent trials of the current data set.⁴ The Simon effect is known to decrease with increasing RT (De Jong, Liang, & Lauber, 1994; Hommel, 1993b). Assuming the putative grouping effect follows a similar time course, the effect of the correspondence between flanker side and response side should also be inversely related to RT. In contrast, different predictions would seem to follow from the attentional-shift hypothesis. One possibility is that there would be a positive relationship between RT and the correspondence of flanker side and response side. This prediction is based on the hypothesis that on trials with relatively slow RTs, there is more time for attention to shift in the direction of the response and thus influence the ongoing response-selection process. Alternatively, there may be no relationship between RT and the correspondence effect if one assumes that the attentional shift is time-locked to the selection of the overt response. According to this hypothesis, attentional shifts occur more rapidly on trials with fast RTs than on trials with slow RTs.

Following the analysis of De Jong et al. (1994), we divided the distribution of congruent trial reaction times into five equal quantiles for each participant for the two levels of correspondence. We calculated the difference between trials in which the distractor was on the response side from trials in which the distractor was on the opposite side, using the means for each quantile. Contrary to the prediction based on the perceptual-grouping hypothesis, the results show that the difference between the corresponding and noncorresponding conditions increases with RT, $F(4, 56) = 7.66, p < .001$. For the fastest quantile, the difference was only 5 ms; for the slowest quantile, the difference was 40 ms, and the function was monotonic. We also performed a similar analysis on the incongruent trials. As noted above, the perceptual-grouping hypothesis does not predict an effect of distractor-response correspondence here. The results for this comparison are ambiguous. The difference between the corresponding and noncorresponding conditions was greatest for the longest RT quantile, with the noncorresponding being faster, a result consistent with one variant of the attentional-shift hypoth-

esis. However, the 8-ms increase was not significant (from 3 ms to 11 ms), $F(4, 56) < 1$.

Experiment 2

In Experiment 1, the distractor was always identical to the target on congruent trials. Thus, congruency and grouping were confounded. Experiment 2 was designed to dissociate these two factors. To this end, two colors were assigned to each response and a 4:2 stimulus to response mapping was used. If the target was red or green, the participants were required to press one key, and if the target was blue or yellow, the participants were required to press the other key. In this manner, there were two types of congruent trials: identical, in which the target and distractor were the same color, and different, in which the target and distractor were nonidentical (different) colors. Previous studies with bilateral flankers have shown that RTs are faster on both types of congruent trials compared with incongruent trials, although the effect is slightly reduced for the nonidentical condition (e.g., Cohen & Shoup, 1997; C. W. Eriksen & Eriksen, 1979). Grouping should occur only if one of the distractors is identical in color with the target (i.e., the identical congruent condition). It should not occur in either the different congruent condition nor in the two variants of incongruent trials (e.g., red target with either a blue or yellow distractor). The neutral condition was not included.

A single colored distractor was again presented on each trial, either on the left or right side with a noncolored flanker on the opposite side to maintain symmetry in the displays. The side of the distractor either corresponded to the relative position of the response or to the other side. According to the perceptual-grouping hypothesis, the position of the distractor should be relevant only for the identical congruent condition. For this condition, the congruency effect should be larger when the distractor appears on the same side as the response. In all of the other conditions, the congruency effect should be symmetric. In contrast, the attentional-shift hypothesis predicts an asymmetry in all conditions. On congruent trials, RTs should be faster when the distractor appears on the same side as the forthcoming response because of the facilitated processing of a stimulus linked to the same response. On incongruent trials, RTs should be slower when the distractor appears on the same side because of the facilitated processing of a stimulus linked to the opposite response.

³ To evaluate the validity of this small effect, we submitted the data of Experiments 1 and 2 and the three experiments mentioned in Footnote 1 to a single ANOVA. We used all trials with incongruent distractors on one side and a neutral flanker on the other side, with the keyboard aligned parallel to the display. The analysis involving 112 participants revealed that responses were 5 ms slower when the incongruent distractor appeared on the side corresponding to the side of the response compared with trials in which the incongruent distractor appeared on the noncorresponding side, $t(111) = 3.044, p = .003$.

⁴ We wish to thank Bernhard Hommel for this suggestion.

Method

Participants. Forty-two college students participated in exchange for course credit. Handedness information was inadvertently not collected at the time of testing.

Apparatus and stimuli. The general setup was similar to that used in Experiment 1. The rings were replaced by filled circles, with the diameter of the target circle 0.35° and the diameter of the flanking circles 0.59° . The color values were changed in this experiment to create a set of four, highly discriminable colors: red, green, blue, and yellow. For half of the participants, as in Experiment 1, markers were presented below the target and flankers. For the other half of the participants, no marker was present.⁵

Procedure. The procedure was identical to that used in Experiment 1. An asterisk appeared at the target position at the start of each trial and remained visible for 500 ms. It then disappeared, and the stimulus display was presented 500 ms later. The participants pressed one of two response keys, indicating the color of the target circle. All of the responses were made with the index finger of the right hand, and between trials the participant rested this finger at an intermediate home position. Red and green were always assigned to one response key and yellow and blue to the other response key. The left-right orientation of the response keys was counterbalanced across participants. The trial ended when a response was detected or after 3 s had elapsed. The feedback tone was played on incorrect trials and after omissions.

There were 32 different types of trials (4 target colors \times 4 distractor colors \times 2 distractor positions). Each trial type was presented four times in each experimental block of 128 trials. Participants completed five experimental blocks during a 1-hr session. These blocks were preceded by two practice blocks of 32 trials each.

Results

The data from 4 participants were dropped from the analyses because their mean RTs were considerably higher (over 750 ms) than the overall mean RT (553 ms) and because their latencies were highly variable ($SDs > 400$ ms). For the remaining 38 participants, incorrect trials (2%) were excluded from the RT analyses as were any responses that were more than three standard deviations from the individual means (1% of all trials).

For each condition, the mean RT was computed for each participant, and these data were submitted to a three-way ANOVA consisting of the following variables: congruency (identical congruent, different congruent, and incongruent), distractor position (left or right), and correspondence (distractor on response side or nonresponse side). The main effect for distractor position was not significant, $F(1, 37) = 1.79$, $p = .196$, nor did this variable interact with the other two. There was a significant effect of congruency, $F(2, 74) = 20.32$, $p < .001$, and a significant interaction between the congruency and correspondence variables, $F(2, 37) = 8.33$, $p = .006$. The means and error rates for this interaction can be seen in Figure 3.

We compared the RTs for trials that had a distractor appearing on the same side as the forthcoming response with trials that had the distractor on the other side, separately for the identical congruent, different congruent, and incongruent trials. Both the perceptual-grouping and the attentional-shift

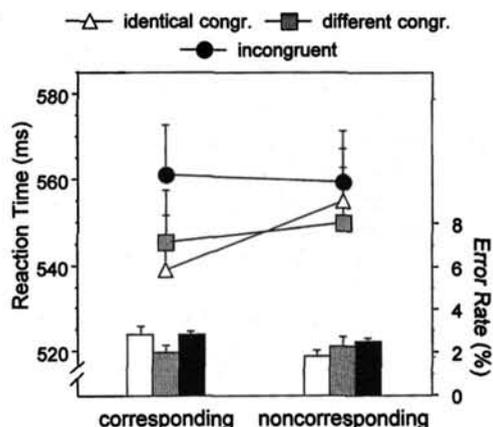


Figure 3. Mean reaction times (lines) and error rates (bars) in Experiment 2 as a function of distractor congruency and correspondence between distractor position and response side. Error bars indicate standard error. congr. = congruent.

hypotheses predict a faster reaction when an identical distractor is presented on the same side as the response. Indeed, a difference of 16 ms could be found, $t(37) = 5.05$, $p < .001$. For the different congruent condition, this difference was only 4 ms. Although this difference was in the direction predicted by the attentional-shift hypothesis, it was not significant, $t(37) = 1.29$, $p = .203$. For incongruent distractors the attentional-shift hypothesis predicts slower RTs for a distractor on the response side. Only a 2-ms difference could be found, a nonsignificant result, $t(37) < 1$, $p = .359$. Thus, these results are in accord with the predictions of the perceptual-grouping hypothesis.

The analysis of errors provides a somewhat different picture. The arcsine-transformed individual accuracy rates were submitted to a two-way ANOVA with variables of congruency and correspondence. We found a significant effect of congruency, $F(2, 74) = 5.2$, $p = .008$. There was also a significant interaction of the variables congruency and correspondence, $F(2, 74) = 3.7$, $p = .028$. There were more errors (3%) when an identical distractor was presented on the response side compared with an identical distractor on the opposite side (2% errors). Thus, the difference in RT in these conditions may in part be due to a speed-accuracy trade-off. The error rates for incongruent and different congruent distractors do not differ for response-side and opposite-side distractors.

Discussion

The results from Experiment 2 are in accord with the predictions of the perceptual-grouping hypothesis. A signifi-

⁵ We included this control variable because we eliminated the markers in intermediate studies (see Footnotes 1 and 3) and wanted to make sure that this had no influence on the results. We included this variable as a fourth factor in the ANOVA, mentioned in the Results section of Experiment 2, and found no significant main effect or interaction involving this variable.

cant asymmetry in the magnitude of the flanker effect was found when the target and distractor were the same color. When the two objects were both linked to the same response but differed in color, the flanker effect was statistically symmetric. This pattern of results is consistent with the hypothesis that the response latencies in the unilateral flanker task reflect two factors. First, there is the basic interaction between the response codes associated with the target and the distractor. This interaction is facilitatory when the two are mapped to the same response, and this interaction produces interference when the two are mapped to different responses. Second, there is a Simon-like effect that arises on account of perceptual grouping. When the distractor and target are identical in color, a perceptual group is created on one side of the display. We assume this creates a task-irrelevant spatial code corresponding to the side of the group. This code interacts with the spatial codes associated with the responses, producing facilitation if the codes are in correspondence and interference if the codes are in conflict.

The attentional-shift hypothesis would also predict an asymmetry on identical congruent trials. By this hypothesis, the observed asymmetry results from the shift of visual attention in the direction of the forthcoming response. The larger flanker effect when the distractor and response side are in correspondence would result from the heightened processing of a distractor on the response side. However, the attentional-shift hypothesis also predicts that this asymmetry should have been observed on the different congruent trials as well. We did not find a significant asymmetry here, although the magnitude of the flanker effect was greater when the distractor and response side were in correspondence. This raises the possibility that both hypotheses may be viable but that the current design was only sufficiently sensitive to detect the effects of perceptual grouping or the combined effects of perceptual grouping and response-based shifts of attention.⁶ An attentional shift would likely produce only subtle effects in the current task, given that the shift can only be triggered after sufficient information has accumulated concerning the forthcoming response. We thus sought more direct evidence for an attentional shift in the following experiment.

Experiment 3

The action-based attentional-shift hypothesis assumes that as a spatially directed response is selected and initiated, attention is shifted in the direction of the forthcoming action. This shift would be functional in the sense that processing from the location of the action would be enhanced (Rizzolatti et al., 1994; Tipper et al., 1992). In the preceding experiments, we looked for evidence of such a shift indirectly, testing whether the interference from peripheral distractors was more potent on the identification of a central target when the distractor was on the same side as the response. An alternative is to directly look for evidence of an attentional shift by comparing processing efficiency at locations either in the direction of the assumed shift or in the opposite direction.

To this end, we designed a dual-task version of a flanker

task. The primary task required the participants to make speeded responses, indicating the color of a central circle. After establishing that perceptual grouping is an important factor, we decided to use a symmetric display to eliminate asymmetric effects of perceptual grouping. The target was thus flanked on the left and right by two larger circles of the same color. This color was again mapped to the same response as the target (identical congruent), mapped to the other response (incongruent), or not mapped to either response (neutral). For the secondary task, the two distractor circles were briefly replaced by two letters, one on each side. After the speeded response on the flanker task was completed, the participants reported the identity of the two letters. Although speed and accuracy were emphasized for the primary task, the participants were informed that only accuracy was being assessed on the secondary, letter-report task.

If attention moves in the direction of the forthcoming response, then letter identification should be better on the side corresponding to this response. This follows from our characterization of response selection and initiation as an interactive accumulation process rather than as a sequential process (C. W. Eriksen & Schultz, 1979; McClelland, 1979). As processing unfolds for a spatially directed response, attention shifts in the direction of the leading candidate and should thus enhance processing from this side. Given that RTs for the flanker task average around 400 ms, one would expect to see the effects of the attentional shift at earlier points in time. To examine the time course of the shift, the letters were presented either 100 ms or 300 ms after the onset of the flanker display. To prevent the participants from delaying processing of the letters until after the speeded response was completed, it was important to mask the letters. In a series of pilot studies, we used a brightness mask, created by simply flipping from the colored circles to the letters and then back to the circles. However, this form of masking did not appear to be very effective. We thus switched to a pattern mask to ensure that processing of the letters would have to take place during the presentation of the flanker displays.

On the other hand, it was also important that the participants perform the flanker task comparably in the 100-ms and 300-ms stimulus onset asynchrony (SOA) conditions. To achieve this goal, a monetary bonus based on performance in this task was implemented. The participants were repeatedly instructed that their bonus depended on how quickly and accurately they responded to the color of the central target.

⁶ Similar to Experiment 1, we performed a distributional analysis on the data from Experiment 2. Contrary to the predictions based on De Jong et al. (1994), the correspondence effect increased with RT for both congruent conditions. For the identical condition, it rose from 10 to 26 ms from the first to fifth quantile, $F(4, 148) = 1.67, p = .161$; for the different congruent condition, it rose from -5 to 16 ms, $F(4, 148) = 2.57, p = .041$. The fact that the distributional analysis is similar for these two conditions is at odds with a simple grouping hypothesis.

Method

Participants. Eighteen students were recruited from the University of California, Berkeley community for this experiment. They received a base pay of \$6 for the 1-hr session and an additional monetary bonus based on their performance on the flanker task. Seventeen of the participants were right-handed, and one was left-handed. All of the participants used their dominant hand for the flanker task.

Apparatus and stimuli. The apparatus was identical to that used in the previous experiments. The target and distractors were circles, identical in size and arrangement to Experiment 2, and these were presented horizontally without the line markers. The distractors could be red, green, or blue, and the target color was selected from a subset of two of these colors. For the letter identification task, a set of eight capital letters was used (*A, S, D, F, G, H, J, and K*), measuring approximately 0.3° in width and 0.4° in height. A number sign (#) of the same size served as the mask.

Procedure. For each participant, two of the colors were designated targets and were mapped in a counterbalanced fashion to the two response keys. This created six possible mappings based on three candidate colors to the two response keys. We controlled the mapping in this experiment to ensure that differences on the letter identification task could not be attributed to the idiosyncratic properties of particular colors. The flankers could be any of the three colors, creating congruent, incongruent, and neutral trials.

Each trial began with the presentation for 500 ms of the fixation mark (the asterisk) at the center of the display. The screen then went blank for 500 ms. Next, the flanker display was presented, with the target circle flanked by two identical distractors, one on the left and one on the right. After an SOA of either 100 ms or 300 ms, a randomly selected pair of two different letters was presented for 28 ms, each letter positioned at the center of one of the flankers. The letters were replaced by the number sign mask. The mask remained visible for 57 ms and was then replaced in turn by the colored flankers. The flanker display was terminated 1 s after its initial appearance. This duration was fixed in order to equate the stimulus displays across the conditions.

The participants made a speeded manual response, pressing one of the two response keys to indicate the color of the target circle. All responses longer than 1 s were counted as omissions, and auditory feedback was given as in the previous experiments. After the speeded response was completed (and feedback was given when required), the participant named the two letters that had been presented, without a specified order and without identifying which letter was left and which was right. When participants reported seeing neither or only one of the letters, they were required to guess, choosing letters from the set of eight potential stimuli. The letter responses were entered by the experimenter using the computer keyboard. The experimenter was seated in a position that prevented him or her from seeing the computer screen. No immediate feedback was given on the letter task. The next trial began after an intertrial interval of 1 s.

There were 12 types of trials (2 target colors \times 3 distractor colors \times 2 SOAs). The session began with two training blocks, consisting of 24 trials each. The first training block was intended to acquaint the participant with the stimulus-response mapping and the basic procedure for the flanker task. Although the letters were presented here, the participant was not asked to respond to them (and, indeed, it appeared that most of the participants were unaware of the letters during this phase). The secondary task was then described, and the participants completed a training block under dual-task conditions. Nine experimental blocks of 48 trials each followed the two training blocks. For each trial, the participant made speeded responses on the flanker task and reported the two

letters. At the end of each experimental block, the participant was given a short break and received summary feedback concerning median RT on the flanker task, accuracy on both tasks, and a tally of the bonus money accumulated during that block. The bonus was calculated as follows: \$0.60 was paid whenever the median RT for a block was faster than the previous lowest median RT, with this amount reduced to \$0.20 and \$0.10 if participants came within 30 ms or 60 ms of this standard. Two cents were subtracted from the bonus for every error on the flanker task.

The contrast of the letters was adjusted to avoid both floor and ceiling effects on the letter identification task. The initial setting for all of the participants was a moderately bright white. If performance on the letter task fell below 70% correct on any block, the contrast was increased; if performance was above 90%, the contrast was decreased. It turned out that these adjustments were rarely required because performance usually fell between these two bounds.

Results

We first consider the results of the flanker task. Incorrect responses were recorded on 7% of the trials. A two-way ANOVA was performed on the remaining data with the following variables: congruency (congruent, neutral, and incongruent) and SOA (100 ms and 300 ms). This analysis revealed a significant main effect of congruency, $F(2, 34) = 34.4, p < .001$, with the mean RT on congruent trials being faster than on incongruent trials (403 ms vs. 440 ms) and the mean RT on neutral trials falling between these two values (416 ms). The error data followed this same pattern: The mean error rates for the congruent, neutral, and incongruent trials were 3.9%, 6.3%, and 11.3%, respectively, $F(2, 34) = 26.73, p < .001$. The higher error rates observed in this study compared with Experiments 1 and 2 presumably reflect the dual-task requirements, although there are other substantial differences.

There was a main effect of SOA in the RT data, $F(1, 17) = 25.9, p < .001$. The mean RT was 13 ms faster in the 100-ms condition. The cause of this difference is unclear. One possibility is that the onset of the letters increased arousal. Alternatively, the effect may reflect specific interactions between the primary and secondary tasks, such as a tendency to delay responding to the colored target until the letters had been presented and identified or greater temporal overlap between key processing stages associated with the two tasks at the longer SOAs (see Hommel & Schneider, 1998). There was a marginally significant difference in error rates between the two SOA conditions, $F(1, 17) = 4.32, p = .053$. Participants made more errors on the flanker task in the 100-ms SOA condition (8%) than in the 300-ms SOA condition (6%). The interaction between congruency and SOA was not significant for the RT, $F(2, 34) = 1.04$, nor for the error data, $F(2, 34) < 1$.

The main data of interest in this experiment are the letter identification rates. In every trial two letters were reported, so that a maximum of 864 letter reports per participant could be evaluated. Mean accuracy was calculated for each participant and each cell of a four-way design with the variables of side (left or right letter), congruency of the distractor, SOA, and correspondence. For the latter, the letter responses were assigned to one of two categories on the

basis of whether the letter had appeared on the same side or on the opposite side as the response. These data were subjected to a four-way ANOVA. Because the distribution of the accuracy data was not skewed, we used the raw values rather than an arcsine transformation. There was no main effect of side, $F(1, 17) = 1.28, p = .274$, although mean accuracy was slightly greater for letters appearing on the right side (78%) compared with those appearing on the left side (74%). There was a main effect of congruency, $F(2, 34) = 5.3, p = .010$, with overall accuracy higher (78%) on congruent trials in comparison with either the neutral (74%) or incongruent (76%) trials.

Most important, a main effect was found for correspondence, $F(1, 17) = 7.30, p = .015$. Identification was more accurate for the letters appearing on the same side as the key used to respond on the flanker task (Figure 4, upper panel). There was also a significant Side \times Correspondence interaction, $F(1, 17) = 7.87, p = .012$. The effect due to the correspondence between the side of the primary task response and the side of the letter was more pronounced for the letters appearing on the left side of the displays.

The main effect of SOA was not significant, $F(1, 17) < 1$, nor were any of the interaction terms. However, as can be seen in Figure 4, the response-side advantage on the letter identification task was only really evident with the 100-ms SOA. The interaction between SOA and correspondence was marginally significant, $F(1, 17) = 3.73, p = .070$. Tests for simple effects indicated a reliable difference between same-side and different-side letter identification performance at the 100-ms SOA, $t(17) = 3.26, p = .005$, but not at the 300-ms SOA, $t(17) < 1, p = .28$.

Discussion

Experiment 3 provides direct evidence for an attentional shift induced by the spatial characteristic of the forthcoming

response. Letters presented on the same side as the flanker response were identified with greater accuracy compared with letters presented on the opposite side of the flanker response. This asymmetry is especially intriguing given that the displays used in the current experiment were balanced. By using bilateral distractors that were identical, the displays themselves should not have biased processing in one direction or the other. This suggests that the asymmetry must reflect the internal dynamics of attention. Our hypothesis is that as a response is being selected and prepared, visual attention shifts in the direction of the candidate response. A consequence of this shift is that processing asymmetries will emerge, reflecting this dynamic change in the focus of attention.

Although the SOA \times Correspondence interaction was only marginally significant, the pattern of results suggests that this action-based shift of attention was most pronounced at the 100-ms SOA. A priori, we expected that asymmetries related to the direction of the forthcoming response would be greatest at the long SOA because it would be at this point that the spatially directed response would be most specified. The fact that the asymmetry was smaller and perhaps even absent in the 300-ms SOA condition may indicate that the participants were able to overcome the action-induced displacement of attention, refocusing on the center of the display in accord with the experimental instructions.

We replicated the results of Experiment 3 in another experiment that was identical to that described above except that the SOAs between the onset of the primary task color patches and the onset of the letters was either 100 ms or 200 ms. With the 100-ms SOA, mean accuracy for reporting the letter on the response side was 75%, whereas the comparable value for the letters on the opposite side was 72%, a reliable difference, $t(12) = 3.0, p = .011$. In the 200-ms SOA condition, no difference was obtained (74% for the response side vs. 73% for the opposite side). Thus, we were able to replicate both the advantage in reporting the response-side letters and the fact that this advantage is only manifest at the short SOA.

Experiment 4

To seek converging evidence for a response-based shift of attention, we used a different dual-task method in Experiment 4. In this study, the primary task again required participants to identify as rapidly as possible the color of a disk, presented at fixation. Unlike the previous experiments, this target was not flanked by colored distractors. Rather, two visual streams were presented, one on the left side and one on the right side. Most of the stimuli in the two streams were digits. Intermingled with these digits were two letters, and for the secondary task, the participants had to report the identity of these letters. The two letters always appeared simultaneously, and we varied the SOA between the onset of the color patch and the letters from 100 to 500 ms.

The rapid serial visual presentation (RSVP) technique has been used to examine the temporal characteristics of perceptual and attentional processes (e.g., Raymond, Shapiro, & Arnell, 1992). We expected to observe an advantage on the

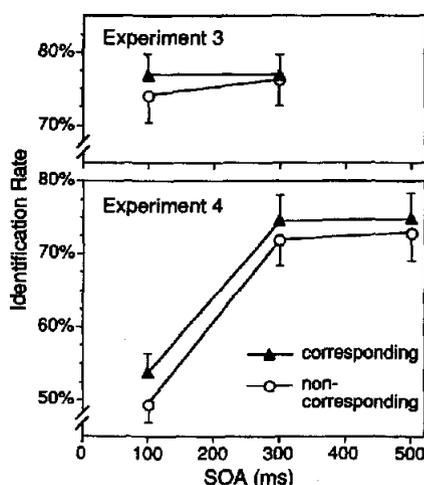


Figure 4. Identification rates in the letter task of Experiment 3 (upper panel) and Experiment 4 (lower panel) as a function of correspondence between letter position and response side and stimulus onset asynchrony (SOA) between colored target and letter. Error bars indicate standard error.

secondary task for letters appearing on the same side as the primary task response, at least for the short SOAs. This method also allowed us to plot the time course of response-based attentional shifts over a longer window, extending beyond the execution of the speeded primary task response.

Method

Participants. Twelve right-handed students from the University of Göttingen, Germany, participated in this experiment. They received 12 DM for participation.

Apparatus and stimuli. The experiment was run on an Apple Performa 630 computer with a 14-in. (35.6-cm) Apple color monitor with 640×480 pixel resolution. Responses were made on the computer keyboard. The keys used measured 1.3×1.3 cm and were a 1.2-cm distance from each other. The participants rested their heads on a chin rest, maintaining a constant distance of 50 cm from the screen. The central color patch subtended a visual angle of 0.92° . The letters were taken from a target set of 22 capital letters, that is, all the letters of the alphabet excluding *W*, *M*, *I*, *Q*, and *O*. The letters measured 0.92° in height and 0.69° in width and were presented on the left or right side with a 1.26° edge-to-edge distance between them and the central color target.

Procedure. Each trial began with the presentation of a fixation mark (0.34° diameter) at the center of the display for 400 ms. The fixation mark was then extinguished, and after 400 ms, the two RSVP streams commenced. Each digit was presented for 50 ms, and the SOA between successive digits was 100 ms (10-Hz RSVP rate). The events in the two streams were synchronized. After a random number of three to six digits, the central color target was presented, appearing simultaneously with the next digit pair. The color target was either red or green. The participants were instructed to respond as fast as possible to the central color patch using two horizontally aligned response keys. The mapping of colors to the response keys was counterbalanced across participants.

The central target stayed on until the end of the trial, whereas the RSVP streams continued to change at the 10-Hz rate. Either one item (100 ms), three items (300 ms), or five items (500 ms) after the presentation of the central target, the digits were replaced on both sides by letters drawn at random from the target set. On every trial, seven items were presented after the onset of the central color target, so that at least two digits were presented after the presentation of the two letters. After the trial any incorrect or omitted response to the RT task was followed by a 1,000-Hz tone. The participant was then required to report the two letters, typing them on the computer keyboard. The letter responses were restricted to the target set.

Training was comparable to that used in Experiment 3, beginning with the primary task alone and then followed by dual-task training. This was followed by seven experimental blocks of 48 trials each. Feedback concerning the mean RT and accuracy on both tasks was given after each block.

Results

All trials with an incorrect response on the primary task (4%) as well as all trials with an RT above 700 ms (2.4%) were eliminated from further analysis. This was done to make sure that on all evaluated trials, response initiation was performed within a comparable time span. A two-way ANOVA was performed on the mean RTs with the variables of SOA and side of response (left or right key press). As in

Experiment 3, a significant effect of SOA was observed on the RT data, $F(2, 22) = 3.73$, $p = .040$. Response latencies were slowest in the 300-ms SOA condition (423 ms) and faster in both the 100-ms and 500-ms SOA conditions (414 ms and 417 ms, respectively). The source of this nonmonotonic effect is unclear. The variable side of response was not found to have any significant effect, $F(1, 11) < 1$, nor was there an interaction between these two variables.

The accuracy data of the letter task was submitted to a three-way ANOVA with the following variables: SOA, side (letter on left or right), and correspondence (referring to the correspondence between the side of the letter and the side of the primary task response). There was no significant effect of side, $F(1, 11) = 3.70$, $p = .081$, although accuracy was slightly better for the left (67%) than for the right (65%) letter. We found a strong effect of SOA in this experiment. Accuracy in the letter task was much lower 100 ms after the onset of the target (52%) compared with the 300-ms and 500-ms SOA conditions (73% and 73%), $F(2, 22) = 29.77$, $p < .001$. Most important, the main effect of correspondence was again observed, $F(1, 11) = 8.36$, $p = .015$. At an SOA of 100 ms, letters on the side of the forthcoming response were reported more accurately (54%) than letters in the opposite position (49%), $t(11) = 2.34$, $p = .029$. This 4% advantage was attenuated at higher SOAs (Figure 4, lower panel), although the SOA \times Correspondence interaction was not significant.

Discussion

Using the RSVP method, the results of Experiment 4 provide further evidence of a response-based shift of visual attention. Accuracy on the letter report task was better for letters appearing in the RSVP stream on the same side as the speeded response. As in Experiment 3, this effect was, at least numerically, largest at the 100-ms SOA, suggesting that the effect is relatively transient. Nonetheless, the results indicate that the focus of attention is altered by the direction of a response and that this shift results in enhanced processing of information emanating from that side of space.

A particularly salient effect in the present experiment was the large decrement in letter report performance for the short SOA condition. This time-dependent decrement is similar to that observed in studies of the psychological refractory period (Pashler, 1994) and the attentional blink (Chun & Potter, 1995; Raymond et al., 1992). In such experiments, a reduction in performance is observed for responses to stimuli that appear in close temporal proximity to a preceding stimulus that requires either a speeded response (psychological-refractory-period studies) or unspeeded response (attentional-blink studies). Recent investigations indicate that similar limitations in processing are associated with the attentional blink and the psychological refractory period (Jollicœur & Dell'Acqua, 1999). Although our results show an interaction between the processing stage of response selection and the stage of stimulus identification, this is not the focus of our current investigation. The important finding in this article lies in the specific interaction between these two stages, depending on their spatial correspondence.

General Discussion

Over the past 25 years many investigators have used the flanker task to study interactions that arise at different stages of information processing. Almost all of these studies have used symmetric displays in which a central target is flanked by irrelevant distractors. The current series of experiments was initiated to explore how these interactions might be modulated by asymmetric displays in which a single, irrelevant flanker is presented on one side of the target. This work was motivated by the findings of Rafal et al. (1996), who observed that patients with prefrontal lesions show a reduced flanker effect when the distractor is presented contralateral to the target. Our first experiment was designed to explore the possibility that maintenance of response codes for lateralized stimuli is primarily done by the contralateral hemisphere. We therefore assumed that the response codes generated in one hemisphere would have a stronger effect on responses made with the contralateral hand. The results did not support this hypothesis. Unexpectedly, however, this experiment revealed another asymmetry: The flanker effect was most pronounced when the distractor appeared on the same side as the forthcoming response.

In subsequent experiments, we explored two factors that may underlie this phenomenon. One factor is the effect of perceptual grouping on the perceived position of the target. This perceptual-grouping hypothesis states that when the target and one of the distractors are identical, participants group them together and assign a spatial tag to the group. This spatial code is toward the side of the distractor of this group. Consequently, it could lead to a form of the Simon effect (e.g., Simon & Small, 1969). That is, participants might be faster when the location of the response corresponds to the location of the perceptual group. The second factor concerns possible effects of the response's location on visual attention. The notion of this action-based attention hypothesis is that when a left-side response is required, visual attention would also move in that direction, creating an asymmetry in terms of the attentional resources allocated to distractors appearing to the left of the target relative to those appearing to the right. We discuss the evidence for and implications of each of the two hypotheses in turn.

The Perceptual-Grouping Hypothesis

Experiment 2 provided direct support for this hypothesis. Asymmetric flanker effects were found only when the target and distractor were identical in color. No statistically significant asymmetries were observed on congruent trials in which the target and distractor were different in color but mapped to the same response key. This hypothesis is in accord with numerous studies demonstrating that task-irrelevant stimulus dimensions (e.g., spatial position) can influence RT when they overlap with the dimensions of the response codes (e.g., Kornblum, 1994).

The modulating role of grouping effects has been examined in previous experiments with the flanker task (Baylis & Driver, 1992; Harms & Bundesen, 1983). In these studies the focus was on whether interference effects were enhanced

when distractors shared a task-irrelevant property with the target: For example, when responding on the basis of color, would the flanker effect be larger between distractors that moved in correspondence with the target? The effects of grouping in the current studies emphasize another form in which dynamic links occur between perception and action. Perceptual grouping leads to a spatial tag of the entire group, and this in turn affects the efficiency of different actions with preference to actions whose spatial tag corresponds to that of the perceptual group.

The Attentional-Shift Hypothesis

Experiment 2 provided support for the perceptual-grouping hypothesis, but it did not support the action-based attention hypothesis. Although both Experiments 1 and 2 showed a trend for asymmetric effects on incongruent trials, significant asymmetries were observed only when the target and distractor were identical. If one combines the data of Experiment 1, Experiment 2, and the three other unreported studies described in Footnote 1, the asymmetry on incongruent trials appears to be small but reliable (see Footnote 3). We suspect, therefore, that the influence of action-based shifts of attention are likely to play a minor role in the RT to the target since the shift is only triggered once a spatial response code has accumulated sufficient activation. Experiment 3 was designed to provide a more direct test of the attentional-shift hypothesis. Here we tested whether the identification of a secondary stimulus depended on the relationship between the position of this stimulus and the direction of the response on the flanker task. The results showed the predicted interaction, with letter identification being slightly higher when the position of the letter was in correspondence with the direction of the flanker response. Because this is a novel finding, we tested this hypothesis with a different design in Experiment 4 to provide converging evidence for it. In Experiment 4, participants were required to make a speeded response to a central target while two streams of stimuli were presented on the two sides. As in Experiment 3, the identification of the letters was higher at the side of the response required for the central target.

The attentional-shift hypothesis highlights the intimate link of attention to motor systems (Rizzolatti et al., 1994; Tipper et al., 1992). Attention seems to be drawn to the location of a forthcoming action. Such a mechanism would obviously have important functional consequences. When preparing to reach for a glass of water, it is useful that the focus of attention be directed not to the initial position of the hand but to the location of the glass. This mechanism explains why a distractor at a position corresponding to the direction of a forthcoming response would exert stronger interactions with a centrally positioned target.

Unknown to us and independent of our study, Hommel and Schneider (1998) conducted a study by using a similar paradigm. In their experiments, participants had to respond to a high- or low-pitch tone by pressing a left or right key. Using varying SOA after the tone, Hommel and Schneider briefly presented an array of four letters, of which one was marked by a vertical line. As a secondary task, participants

reported the marked letter after the trial. Their results were comparable to ours. At short SOAs, the identification rates for letters on the side corresponding to the spatial characteristic of the response were higher, whereas at longer SOAs, this effect disappeared. Our findings, as well as those of Hommel and Schneider, focus on the connection between attention and action and its subsequent effect on perceptual processing (as exemplified by the superior identification of letters at the side of the previous action). Prinz (1990) and Hommel (1996) have argued that perception and action are linked because these processes share common codes. For example, a spatially directed response to a certain position shares the same spatial code as the perception of an object at that location. When the spatial code for the response is activated, the letter connected to the same code is more likely identified and reported.

Hommel and Schneider (1998) proposed that the effect results from two events accessing a similar spatial code. We have emphasized an account based on attentional shifts triggered by planned actions. Given the emphasis on common representational codes for perception and action, there are obvious similarities between these two hypotheses. However, it would also appear that the two hypotheses diverge in the processing consequences of these links. For example, the attentional-shift hypothesis would predict facilitated perception for information presented at a location sharing a code with the activated response. The common coding hypothesis would predict facilitated perception for information that accesses the relevant spatial code, even if that information is presented at a different location. Evaluating the merits of these two hypotheses is a challenge for future study.

References

- Baylis, G. C., & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. *Perception & Psychophysics*, *51*, 145–162.
- Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 109–127.
- Cohen, A., Ivry, R. B., Rafal, R. D., & Kohn, C. (1995). Activating response codes by stimuli in the neglected visual field. *Neuropsychology*, *9*, 165–173.
- Cohen, A., & Shoup, R. (1997). Perceptual dimensional constraints on response selection processes. *Cognitive Psychology*, *32*, 128–181.
- Coles, M. G. H., Gratton, G., Bashore, T. R., Eriksen, C. W., & Donchin, E. (1985). A psychophysiological investigation of the continuous flow model of human information processing. *Journal of Experimental Psychology: Human Perception and Performance*, *11*, 529–553.
- De Jong, R., Liang, 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.
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics*, *16*, 143–149.
- Eriksen, C. W., & Eriksen, B. A. (1979). Target redundancy in visual search: Do repetitions of the target within the display impair processing? *Perception & Psychophysics*, *26*, 195–205.
- Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception & Psychophysics*, *25*, 249–263.
- Frith, C. D. (in press). The role of dorsolateral prefrontal cortex in the selection of action. In S. Monsell and J. Driver (Eds.), *Attention and performance XVIII*. Cambridge, MA: MIT Press.
- Gattass, R., Sousa, A. P. B., & Gross, C. G. (1988). Visuotopic organization and extent of V3 and V4 of the macaque. *Journal of Neuroscience*, *8*, 1831–1845.
- Grabowecky, M., Robertson, L. C., & Treisman, A. (1993). Preattentive processes guide visual search: Evidence from patients with unilateral visual neglect. *Journal of Cognitive Neuroscience*, *5*, 288–302.
- Harms, L., & Bundesen, C. (1983). Color segregation and selective attention in a nonsearch task. *Perception & Psychophysics*, *33*, 11–19.
- Hommel, B. (1993a). Inverting the Simon effect intention: Determinants of direction and extent of effects of irrelevant spatial information. *Psychological Research*, *55*, 270–279.
- Hommel, B. (1993b). The relationship between stimulus processing and response selection in the Simon task: Evidence for a temporal overlap. *Psychological Research*, *55*, 280–290.
- Hommel, B. (1995). Attentional scanning in the selection of central targets from multi-symbol strings. *Visual Cognition*, *2*, 119–144.
- Hommel, B. (1996). The cognitive representation of action: Automatic integration of perceived action effects. *Psychological Research*, *59*, 176–186.
- Hommel, B., & Schneider, W. X. (1998). Visual attention and manual response selection: Distinct mechanisms operating on the same codes. Manuscript submitted for publication.
- Ivry, R. B., Cohen, A., Diedrichsen, J., & Danziger, S. (1997). [Asymmetries in a unilateral flanker task]. Unpublished raw data.
- Jolicœur, P., & Dell'Acqua, R. (1999). Attentional and structural constraints on visual encoding. *Psychological Research*, *62*, 154–164.
- Kornblum, S. (1994). The way irrelevant dimensions are processed depends on what they overlap with: The case of Stroop- and Simon-like stimuli. *Psychological Research*, *56*, 130–135.
- Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility—A model and taxonomy. *Psychological Review*, *97*, 253–270.
- 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.
- McClelland, J. L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review*, *86*, 287–330.
- McGlinchey-Berroth, R., Milberg, W. P., Verfaellie, M., Alexander, M., & Kilduff, P. T. (1993). Semantic processing in the neglected visual field: Evidence from a lexical decision task. *Cognitive Neuropsychology*, *10*, 79–108.
- Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin*, *116*, 220–244.
- Prinz, W. (1990). A common coding approach to perception and action. In O. Neumann & W. Prinz (Eds.), *Relationships between perception and action* (pp. 167–201). Berlin, Germany: Springer-Verlag.
- Rafal, R., Gershberg, F., Egly, R., Ivry, R., Kingstone, A., & Ro, T.

(1996). Response channel activation and the lateral prefrontal cortex. *Neuropsychologia*, 34, 1197-1202.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, 18, 849-860.

Rizzolatti, G., Riggio, L., & Sheliga, B. M. (1994). Space and selective attention. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 232-265). Cambridge, MA: MIT Press.

Simon, J. R., & Small, A. M., Jr. (1969). Processing auditory

information: Interference from an irrelevant cue. *Journal of Applied Psychology*, 53, 433-435.

Tipper, S. P., Lortie, C., & Baylis, G. C. (1992). Selective reaching: Evidence for action-centered attention. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 891-905.

Wallace, R. J. (1971). S-R compatibility and the idea of a response code. *Journal of Experimental Psychology*, 88, 354-360.

Received October 30, 1998
 Revision received February 16, 1999
 Accepted February 16, 1999 ■



**AMERICAN PSYCHOLOGICAL ASSOCIATION
 SUBSCRIPTION CLAIMS INFORMATION**

Today's Date: _____

We provide this form to assist members, institutions, and nonmember individuals with any subscription problems. With the appropriate information we can begin a resolution. If you use the services of an agent, please do NOT duplicate claims through them and directly to us. **PLEASE PRINT CLEARLY AND IN INK IF POSSIBLE.**

PRINT FULL NAME OR KEY NAME OF INSTITUTION _____		MEMBER OR CUSTOMER NUMBER (MAY BE FOUND ON ANY PAST ISSUE LABEL) _____
ADDRESS _____		DATE YOUR ORDER WAS MAILED (OR PHONED) _____
CITY _____	STATE/COUNTRY _____	ZIP _____
YOUR NAME AND PHONE NUMBER _____		PREPAID <input type="checkbox"/> CHECK <input type="checkbox"/> CHARGE <input type="checkbox"/>
		CHECK/CARD CLEARED DATE: _____
		(If possible, send a copy, front and back, of your cancelled check to help us in our research of your claim.)
		ISSUES: <input type="checkbox"/> MISSING <input type="checkbox"/> DAMAGED
TITLE _____	VOLUME OR YEAR _____	NUMBER OR MONTH _____
_____	_____	_____
_____	_____	_____

Thank you. Once a claim is received and resolved, delivery of replacement issues routinely takes 4-6 weeks.

(TO BE FILLED OUT BY APA STAFF)

DATE RECEIVED: _____	DATE OF ACTION: _____
ACTION TAKEN: _____	INV. NO. & DATE: _____
STAFF NAME: _____	LABEL NO. & DATE: _____

Send this form to APA Subscription Claims, 750 First Street, NE, Washington, DC 20002-4242

PLEASE DO NOT REMOVE. A PHOTOCOPY MAY BE USED.