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# Spatial asymmetries in the flanker-congruency effect: Attentional scanning is biased by flanker orientation

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## Summary

If targets are flanked by congruent or incongruent distractors, performance is facilitated or impaired, respectively. Prior studies revealed that, with normal letters, this flanker effect is more pronounced with left- than with right-side flankers. The present study shows that the left-side bias is eliminated if the flankers (but not the target) are mirrored (Experiment 1). If the orientation of the stimulus string varies randomly from trial to trial, the asymmetry depends on orientation: Normal letters produce a left-side bias while mirrored letters tend to produce a right-side bias (Experiment 2). Interestingly, these orientation-specific biases are observed only in trials where flanker orientation is repeated but not after a switch in orientation. These results suggest that the asymmetry effect does not reflect target-related processing or on-line selection strategies. Rather, processing flankers of a particular orientation seems to bias the cognitive system to scan subsequent flankers in a particular direction.

Key words: Visual attention, flanker effect, selection, compatibility, spatial asymmetry

One of the most pertinent questions about human attention is on the fate of unattended stimulus information. A very useful tool for investigating this issue is the flanker task that Eriksen and Eriksen (1974) introduced as a “nonsearch task”. Basically, a row of symbols is presented to the subject, the target being located at the center of the row, say at position 3 of a five-letter string. The remaining string elements flanking the target are congruent or incongruent symbols, such as letters that are identical either to the current or the alternate target. Usually, congruent flankers yield faster reaction times and less errors than incongruent ones (e.g., Eriksen & Eriksen, 1974; Miller, 1991). That is, even though they are irrelevant to the task, flankers are processed to a certain degree.

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Explanations of this flanker effect have often pursued an attentional spotlight perspective that likens attention to a spotlight of a modifiable size, directed or attracted to a certain location in space (e.g., Eriksen & Yeh, 1985; LaBerge, 1983; Posner, 1980). Objects falling into the spotlight's focus are selected for further processing, while objects outside of it are excluded. If the focus has a limited resolution, flankers close to the target may fall into the attended field and thus cannot be excluded. Consistent with this expectation, the flanker effect decreases with increasing flanker-target distance (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973; Miller, 1991; St. James, 1990). That is, the focusing of spatial attention may serve to increase (or even determine) the selection probabilities for objects falling into the focused area.

Recent findings on the spatial distribution of the flanker effect suggest, however, that there are (also) other selection mechanisms at work. Specifically, with letters left-side flankers have a stronger impact on performance than right-side flankers (Harms & Bundesen, 1983; Hommel, 1995). If, for instance, a five-letter string contains a central target (position 3), a critical congruent or incongruent letter at position 1, 2, 4, or 5 (from left to right), and neutral letters in the remaining positions, the flanker effect is larger with the critical letter in position 1 or 2 than in 4 or 5. With picture-like symbols, this left-side bias disappears, and it even tends to turn into a right-side bias with mirrored letters (Hommel, 1995), thus ruling out an account in terms of anatomical hardware. Clearly, such a result pattern is not expected from a spotlight view.

Interestingly, spatial asymmetries are a common finding in memory tasks, where shortly presented strings have to be reported as completely as possible. With these whole-report tasks, left-side elements of letter strings are reported more often and with higher accuracy than right-side elements (e.g., Bryden, 1965; Heron, 1957). To account for that, Heron (1957) proposed a fast-working attentional scanning mechanism, perhaps originally developed as a reading skill, that scans string elements in a left-to-right manner. This implies that the left-side bias would be weaker or absent with non-alphanumeric material and reversed with, for example, hebrew readers. In fact, a left-side advantage is less likely with geometric figures than with letters (Bryden, 1960), and turns into a right-side advantage with hebrew readers (Harcum & Friedman, 1963).

Although the correspondence between these whole-report findings and the flanker effect results is obvious, one may doubt whether this is more than an accidental parallel. After all, it is essential for a memory task to attend to as much elements as possible, whereas the flanker task requires the opposite. So, at first sight, there seems to be little reason to scan the stimulus string in a flanker task. However, Hommel (1995) considered two possible roles of a scanning mechanism:

On the one hand, subjects may have difficulties to locate the target within the string. In order to solve this problem, they may employ their reading skills and scan the string from the leftmost position until they reach the target. That is, flanker effect asymmetries may reflect the *strategic* employment of stimulus-specific (e.g., reading) skills. Alternatively, alphanumeric material may *automatically* invoke the scanning mechanism, this producing a conflict between the attempt to direct attention to (or select) the central letter and the reading-like habit to direct attention to (or select) the leftmost letter. In either case, scanning processes could actually come into play in a flanker task, producing flanker effect asymmetries.

Though the results of the Hommel (1995) study strongly suggested that scanning processes are at work in the flanker task, they did not discriminate between the strategy hypothesis and the automaticity hypothesis. So, the aim of the present study was to contrast the two, that is, to test whether the left-side asymmetry is better characterized as due to a voluntarily chosen, task-specific strategy, as indicating an automatic, stimulus-triggered process or, possibly, as reflecting the interaction between stimulus-dependent bottom-up processes and strategy-dependent top-down biases.

## Experiment 1

As pointed out, the spatial distribution of the flanker effect varies with the stimulus material: The left-side bias observed with normal letters is weakened or disappears with pictures and tends to turn into a right-side asymmetry with mirrored letters. On the one hand, the stimulus material may automatically invoke a certain scanning tendency. Thus, letters but not pictures may activate the subject's reading skills, hence, left-to-right scanning, and mirror letters may induce right-to-left scanning. Another possibility is that the employment of scanning or reading skills is a deliberate strategy to overcome the target-localization problem.

According to one version of the strategy hypothesis, one might expect the properties of the target stimulus to be more relevant than flanker properties. If the target is a normal letter, reading-like scanning strategies might be employed, thus producing the left-side asymmetry. This should not depend on the type or orientation of the flankers, as these have to (and can) be, ignored anyhow. That is, normally oriented letter targets should produce a left-side asymmetry independent of whether the flankers are also normally oriented or mirrored. If, however, the stimulus material automatically invoked a material- or orientation-specific scanning process, mirrored flankers would trigger a right-to-left scanning process competing with the left-to-right scanning process triggered by the target. Consequently, the left-side bias should at least be greatly diminished, if not turned into a right-side bias (note, however, that the reversal is not complete even with mirrored targets: Hommel, 1995, Experiment 5).

In Experiment 1, normally oriented target letters were presented among either normally oriented or mirrored letter flankers. According to a strategy hypothesis, this is likely to produce the same left-side bias under both flanker orientations, whereas the automaticity hypothesis predicts a left-side bias with normally oriented flankers but no such bias, or even a right-side bias, with mirrored flankers.

## Method

### *Subjects*

Thirty-three adults were paid to participate in single sessions of about 30 min. They reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment. Sixteen were tested with normally oriented flankers and 17 with mirrored flankers.

### *Apparatus and Stimuli*

Stimulus presentation and data acquisition was controlled by a Hewlett Packard Vectra QS20 computer, attached to an Eizo 9070S (or 9080i) monitor. All stimuli were taken from the CGA text mode font and appeared black-on-white. Subjects responded by pressing the left or right shift key of the computer keyboard with the corresponding index finger.

From a viewing distance of approximately 60 cm, the subject saw a white rectangular field of 5.8° width and 3.3° height. The *y* position of the stimuli was continuously marked by two arrows, 1.2° to the left and right of the center. An asterisk served as fixation mark, which appeared at the target location. The target letter appeared at the geometrical center of the screen. The normally oriented uppercase letters S and K served as targets assigned to the left and right response key, respectively. Each target was flanked by four letters, two on either side. These four letter flankers were all normally oriented in the normal-orientation condition but were mirrored at their vertical axis (i.e., pointing to the left) in the mirror-orientation condition. One of the flankers was either congruent (same letter as the target) or incongruent (same letter as the alternative target), while the remaining three positions were occupied by neutral uppercase Ds. The letters measured 0.3º x 0.4º, so that the whole five-letter stimulus string extended over 1.5º x 0.4º.

### *Design and Procedure*

Each subject was tested in a single session with normal or mirrored flankers only, i.e., flanker orientation varied between groups. Each session comprised 20 blocks, preceded by a warming-up block. Blocks consisted of 16 randomly ordered trials, whose type resulted from the possible combinations of two target letters, two critical flanker letters, and four critical flanker locations. Each trial started after an intertrial interval of 2,000 ms with the presentation of the fixation mark for 100 ms, followed by a 1,000 ms blank interval, before the row of five letters was presented for 150 ms. The program waited up to 1,000 ms for a response. Responses with the wrong key were counted as errors and responses with latencies above 1,000 ms were considered missing. In both cases, auditive error feedback was given, while the trial was recorded and repeated at some random position in the remainder of the block. Subjects were instructed to respond to the central target letter only, as fast and correctly as possible. It was emphasized that flanking letters were irrelevant and should be ignored.

## Results

Missing trials accounted for 0.53% of the data and were excluded from analyses. For each subject, mean reaction times (RTs) and proportions of errors (PEs) were computed as a function of side (left vs. right), eccentricity (inner vs. outer position), and congruence of critical flanker (congruent vs. incongruent), whereas flanker orientation (normal vs. mirrored) was a between-subjects variable. Means are shown in Figure 1.

The significance criterion was set to $p = .05$. The RT analysis revealed significant main effects of flanker eccentricity, $F(1,31) = 22.84$, $MSE = 179.60$, $p < .001$, and congruence, $F(1,31) = 144.49$, $MSE = 321.12$, $p < .001$, and four significant interactions. Most importantly, the significant interaction of congruence and side, $F(1,31) = 6.41$, $MSE = 220.57$, $p < .05$, was further modified by flanker orientation, $F(1,31) = 7.98$, $p < .01$. As indicated in Figure 1 and confirmed by separate analyses, the congruence effect was more pronounced on the left than the right side if the flankers were normally oriented, but there was no asymmetry with mirrored letters. In fact, normal flankers produced a reliable congruence effect in positions 1 ($t(15) = 6.47$, $p < .001$), 2 ($t(15) = 6.63$, $p < .001$), and 4 ($t(15) = 6.13$, $p < .001$) but not in position 5 ($t(15) = 1.39$; $p > .17$), whereas mirrored flankers were effective in all four positions ($t$'s(16) = 2.23, 7.94, 4.25, and 4.16; $p$'s < .05, < .001, < .001, and < .001, respectively).

Two further interactions involved eccentricity. As Figure 1 shows, congruence effects were more pronounced with inner than outer flankers, $F(1,31) = 26.30$, $MSE = 273.45$, $p < .001$, that is, critical flankers near the target had a greater impact than more distant flankers.

Moreover, RTs were highest for critical flankers in position 2 with normal orientation but in position 4 with mirrored flankers, this producing an interaction of orientation, side, and eccentricity, $F(1,31) = 4.63$, $MSE = 241.20$, $p < .05$.

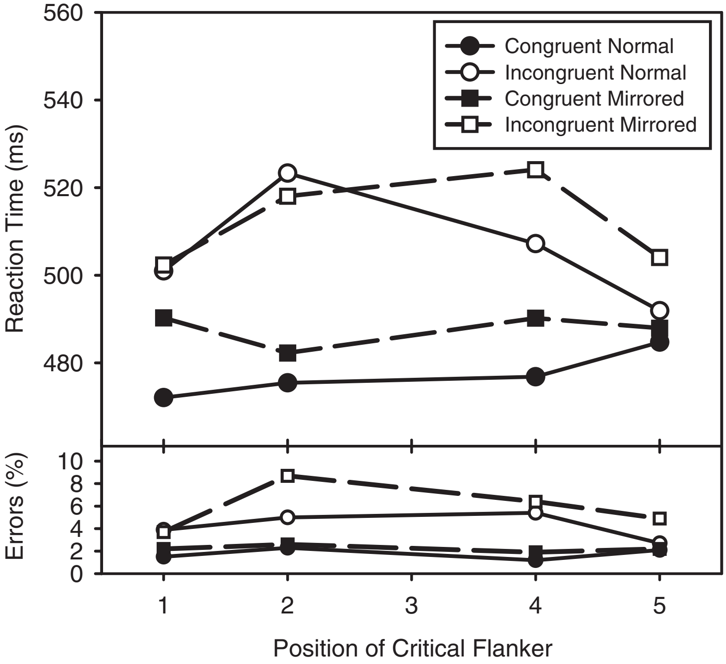

Figure 1:
Reaction times and proportions of errors in Experiment 1 as a function of flanker orientation (normal vs. mirrored), and position (from left to right) and congruence of critical flanker. Note that the target letter was always normally oriented.

The PE analysis produced significant main effects of eccentricity, $F(1,31) = 14.62$, $MSE = 7.62$, $p < .001$, and congruence, $F(1,31) = 26.87$, $MSE = 23.84$, $p < .001$, that also interacted, $F(1,31) = 15.73$, $MSE = 6.87$, $p < .001$, and were involved in a four-way interaction with orientation and side, $F(1,31) = 4.65$, $MSE = 8.59$, $p < .05$. The error pattern followed that observed in the RTs, only that here the congruence effect with mirrored flankers was particularly pronounced in position 2. Separate tests revealed that normal letters produced a reliable congruence effect in all but the fifth position ($t$'s(15) = 2.44, 3.17, 2.80, and 1.32; $p$'s < .05, < .01, < .05, and > .20, respectively), whereas mirrored letters were effective in all but the first position ($t$'s(16) = 1.30, 4.65, 2.93, and 2.12; $p$'s > .20, < .001, < .01, and < .05, respectively).

## Discussion

The previously observed left-side bias in the flanker effect was replicated with normally oriented flankers but was absent with mirrored flankers. This does not support an account of the left-side bias in terms of voluntary strategies, at least not if these strategies are assumed to be independent of flanker orientation. Rather, it seems that the whole stimulus string was analyzed as to the orientation of its elements, and according to the outcome of this analysis a left-to-right or a right-to-left scanning process was triggered. Consequently, left-side flankers were more likely to affect performance with normally oriented flankers, whereas right-side flankers were slightly more effective with mirrored letters.

Why presenting mirrored flankers did not turn the left-side bias into an equally-pronounced right-side bias may be due to several factors. First, mirrored flankers may induce right-to-left scanning to the same degree as normal flankers induce left-to-right scanning. However, as the normally oriented target always triggered a left-to-right process, this would imply more competition between scanning processes with mirrored than with normal flankers, so that the scanning tendencies may have canceled out each other. In fact, we will see in Experiment 2 that the right-side bias is slightly stronger if both flankers and target are mirrored. Second, given the great amount of practice in left-to-right reading (at least in the Western culture), the association between normal letters and rightward scanning may be stronger than that between mirrored letters and leftward scanning. This would fit with the observation that mirroring both flankers and targets does not produce an overly strong right-side bias in the flanker task (Hommel, 1995, Experiment 5) and that spatial asymmetries in whole-report tasks are not completely reversed with mirrored letters (Wolff & Mewhort, 1986). At any rate, the present results are apparently more consistent with an automaticity than with a strategy account of spatial biases in the flanker effect.

## Experiment 2

Although the outcome of Experiment 1 favors the automaticity hypothesis, the empirical basis is not firm. Even though it is not obvious why the orientation of irrelevant distractors should have an impact on strategic decisions of participants in a flanker task, we cannot completely rule out that it had. That is, left-to-right scanning may not have been absent with mirrored flankers because they automatically triggered another process, but because the subjects in the mirror group decided to use another, perhaps more useful strategy.

Experiment 2 was conducted to avoid at least some of these interpretational problems. First, normal and mirrored flankers were used in the same task, so that their impact on target processing could be assessed within subjects. As this design obviated orientation differences between target and flankers, orientation was the same for all members of a stimulus string including the target. Second, string orientation varied randomly and was unpredictable. According to the strategy hypothesis, this should eliminate differences between normal and mirrored flankers. According to the automaticity hypothesis, however, stimulus orientation should automatically trigger an orientation-specific scanning process, thus producing different spatial distributions of the flanker effect for normal and mirrored letters.

Third, mixing flanker orientations allows one to compare conditions under which this orientation is repeated (i.e., when the present flanker orientation matches the orientation of the flankers in the previous trial) with conditions involving a switch of orientation. This analysis should help to disentangle two versions of the strategic hypothesis. One assumes that left-to-right scanning and right-to-left scanning are processes belonging to two different task sets. If so, switching from one set to another should cost measurable time. As flanker orientation varies randomly, subjects are unable to implement the needed task set before the stimulus string is presented, which means that the task-switching costs should contribute to the RT in switch trials. As task-switching costs are known to be considerable (often between 50-150 ms; e.g., Meiran, 1996; Rogers & Monsell, 1995) this leads one to expect that orientation switches produce longer RTs than repetitions. Moreover, task sets are not unlikely to be weaker (e.g., not yet fully implemented) after a task switch, which would suggest that spatial asymmetries might be less pronounced in switch as compared to repetition trials. As an alternative to this set-switching strategy, people may be able to integrate left-to-right and right-to-left scanning processes into the same task set, leaving it to the flanker orientation to trigger scanning direction. If so, one would expect the opposite outcome as with the set-switching version: no main effects of orientation switch and no interaction of switch with spatial asymmetries in the flanker-congruency effect.

## Method

Twelve adults fulfilling the same criteria as in Experiment 1 were paid to participate in single sessions. The method was as in Experiment 1, with the following exceptions. Letter orientation (normal or mirrored) was a random, within-subjects variable, and it was identical for all letters of a stimulus string including the target. Each session comprised 12 blocks, preceded by a warming-up block. Blocks consisted of 32 randomly ordered trials, whose type resulted from the possible combinations of two target letters, two critical flanker letters, four critical flanker locations, and two orientations.

## Results

Missing trials (< 0.5%) were excluded and mean RTs and PEs were computed as a function of orientation, side, eccentricity, and congruence. Means are shown in Figure 2.

A four-way ANOVA of RTs yielded significant main effects of eccentricity, $F(1,11) = 16.34$, $MSE = 229.32$, $p < .001$, and congruence, $F(1,11) = 115.27$, $MSE = 294.68$, $p < .001$. An interaction between these two effects, $F(1,11) = 19.39$, $MSE = 378.58$, $p < .001$, indicated that flankers near the target had again a stronger impact on target processing than more distant flankers. Most importantly, congruence entered into a three-way interaction with side and orientation, $F(1,11) = 6.32$, $MSE = 286.75$, $p < .05$. As indicated in Figure 2, normally oriented strings were associated with larger congruence effects on the left than on the right side, whereas the opposite pattern was obtained with mirrored strings. Planned comparisons showed that, with normal orientation, congruence effects were present in all but the rightmost position ($t$'s(11) = 4.69, 3.12, 3.36, and 1.43; $p$'s < .001, < .01, < .01, and > .17, respectively). With mirrored orientation, flanker effects were reliable at positions 2 ($t(11) = 4.86$, $p < .001$) and 4 ($t(11) = 6.27$, $p < .001$), just missed significance at position 5 ($t(11) = 1.77$, $p < .1$), and were far from significance at the leftmost position ($t(11) = 1.29$, $p > .19$).

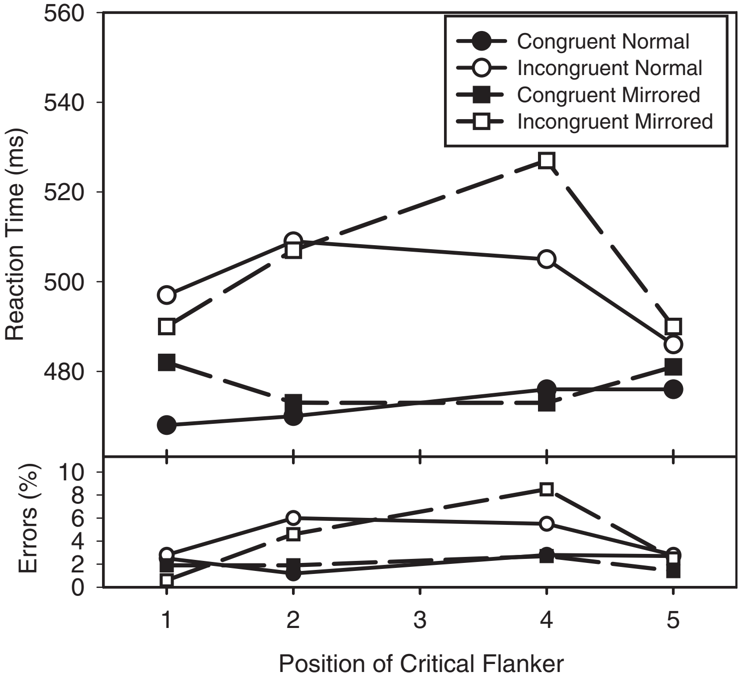

Figure 2:
Reaction times and proportions of errors in Experiment 2 as a function of flanker orientation (normal vs. mirrored), and position (from left to right) and congruence of critical flanker. Note that the target always shared the orientation of the flankers.

The PE analysis produced significant main effects of eccentricity, $F(1,11) = 10.27$, $MSE = 19.21$, $p < .01$, and congruence, $F(1,11) = 17.97$, $MSE = 11.04$, $p < .001$, as well as significant interactions between eccentricity and congruence, $F(1,11) = 12.23$, $MSE = 15.31$, $p < .005$, side and orientation, $F(1,11) = 8.19$, $MSE = 2.17$, $p < .05$, and eccentricity and orientation, $F(1,11) = 5.70$, $MSE = 5.78$, $p < .05$. As Figure 2 illustrates, the errors produced a pattern similar to RTs: More errors were made with inner than outer critical flankers, and this effect was more pronounced with mirror than with normal orientation. Error rates were higher with incongruent than congruent flankers, and this effect was larger with inner than outer critical flankers. With normal orientation, more errors were made with critical flankers on the left than on the right side while the opposite was true with mirrored letters.

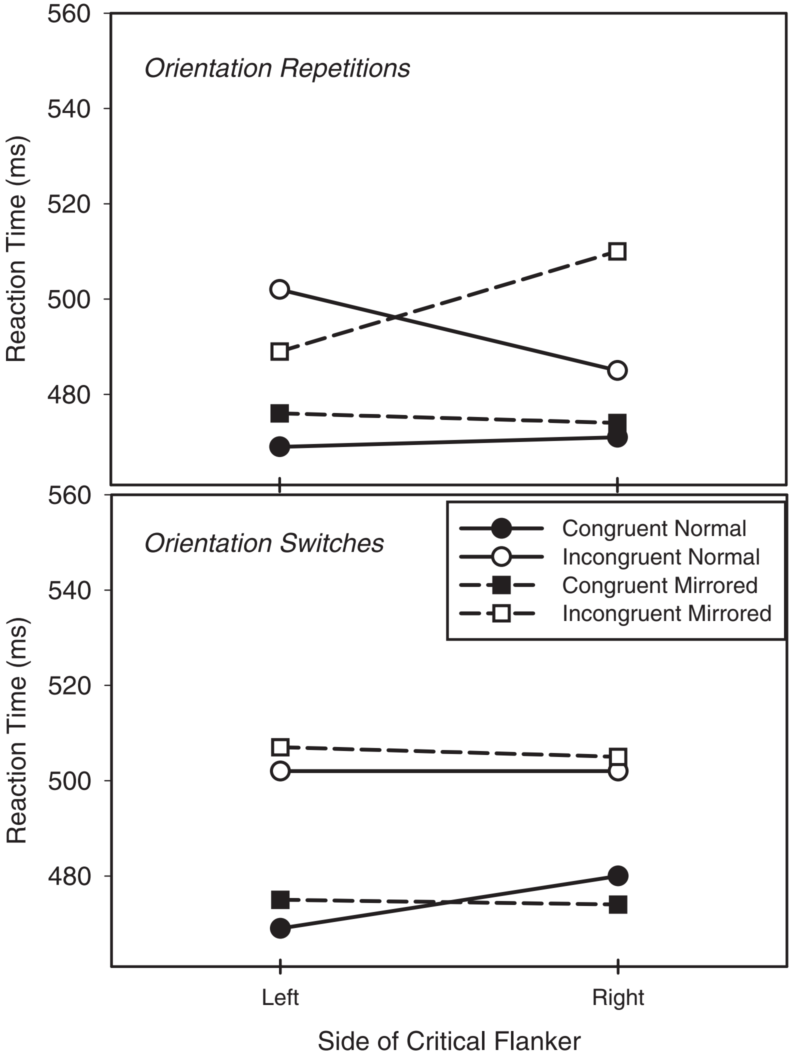

Figure 3:
Reaction times in Experiment 2 as a function of repetition vs. switch of flanker orientation, flanker orientation (normal vs. mirrored), and side and congruence of critical flanker.

Sequential effects were analyzed by calculating individual mean RTs as a function of congruence and side of critical flanker, flanker orientation, and repetition vs. switch of flanker orientation. Only correct trials were analyzed and repetitions or switches were only considered if the present *and* the previous trial were correct. The ANOVA of these data revealed only one reliable effect involving the orientation-switch variable: a main effect of repetition/switch, $F(1,11) = 5.60$, $MSE = 214.32$, $p < .05$, indicating a 5-ms benefit for orientation repetitions as compared to switches. However, as the theoretically central four-way interaction approached the 17% level, separate three-way ANOVAs with congruence, side, and orientation as factors were run for orientation repetitions and orientation switches. As obvious from Figure 3, the three-way interaction was restricted to trials involving the repetition of flanker orientation, $F(1,11) = 7.65$, $MSE = 350.37$, $p < .05$, but was absent with orientation switches, $p > .5$.

### Discussion

The results show an articulate left-side asymmetry of the flanker effect with normal letters and a right-side asymmetry with mirrored letters. The reversal from left- to right-side bias was slightly more pronounced than in Experiment 1, but again far from perfect. On the one hand, this pattern suggests a role of competition between target- and flanker-triggered scanning processes in the mirror condition of Experiment 1. On the other hand, though, the fact that the reversal is incomplete even if target and flanker imply the same scanning direction – as in the present mirror condition – shows that competition cannot be the whole story. Apparently, mirrored letters suggest leftward scanning processes less strongly or consistently than normal letters suggest rightward scanning processes.

At any rate, it is clear that letter orientation did systematically modify the spatial bias in the flanker effect. Given that subjects could not know the orientation of the stimulus string before its onset, and given that the time between stimulus onset and response selection was too short to make general strategic decisions in addition to solving the task, this modification and, hence, the spatial bias does not seem to reflect an on-line voluntary processing strategy. The same conclusion is suggested by the analyses of sequential effects. The set-switching version of the strategy hypothesis would predict considerable switching costs if the flanker orientations of the present and the previous trial do not match. Even though a tiny but reliable switching cost was observed, its size is of a clearly different order of magnitude than what is commonly observed in task-switching studies (e.g., Meiran, 1996; Rogers & Monsell, 1995). This makes it unlikely that orientation switches required a (re-) implementation of directional-scanning processes before the target could be selected.

A purely bottom-up interpretation does not fare much better. Whereas the absence of considerable switching costs is consistent with the idea that flanker orientation triggered directional scanning processes automatically, it is difficult to see why only repeated flanker orientations should have done so – and the same objection applies to the integrative version of the strategy hypothesis considered above. Indeed, if flankers are unable to impact directional scanning in switch trials at all they do not seem to trigger scanning routines directly, that is, in a bottom-up fashion. Instead, processing flankers of a particular orientation seems to induce a tendency to scan the *next* stimulus string in a particular direction or order. In other words, processing irrelevant stimuli can induce a kind of temporary task set that biases the cognitive system to process subsequent information in particular ways.

## General Discussion

The present study examined why the size and occurrence of the flanker effect depends on the spatial position of the critical (i.e., congruent or incongruent) flanker. Experiment 1 showed that the left-side bias observed with normal letters disappears if the flankers are mirrored, even if the target is normally oriented. This suggests that at least some flankers, despite their task-irrelevance, are analyzed as to their orientation, this inducing and supporting different scanning processes for normally oriented and mirrored flankers. Experiment 2 investigated the possibility that subjects had voluntarily chosen flanker-related scanning strategies in Experiment 1. Although stimulus orientation varied unpredictably from trial to trial, normally oriented strings (or flankers) still produced a left-side bias while mirrored strings produced a right-side bias. That is, the letter strings were processed differently depending on the orientation of their elements.

However, this was the case only if the flankers' orientation was the same as in the preceding trial. This observation raises doubt in any kind of on-line interpretation, be it in terms of bottom-up or top-down control: Pure bottom-up control should have been less sensitive to the history of flanker orientations (or the direction in which they were scanned) than the outcome of Experiment 2 suggests, whereas on-line top-down control should have been more sensitive, i.e., should have produced more substantial switching costs. The observation that orientation switches were not associated with (pronounced) immediate costs but nevertheless eliminated spatial asymmetries in the flanker effect suggests a more interactive scenario.

To create such asymmetries, the processing system apparently needs to be in a particular set or state that favors a particular scanning direction. This state may be supported by, but does not seem to stem from active task preparation: General preparation at the beginning of the task should not have been sensitive to trial-to-trial variations in flanker orientation and more specific trial-to-trial preparation should have created more pronounced switching costs. Rather, the respective state seems to be a residue left over by the processes in the previous trial, that is, a trace that is sufficiently inert to affect the subsequent trial (Allport, Styles, & Hsieh, 1994). However, this trace does not autonomically determine the direction in which stimuli are scanned in the next trial, otherwise the spatial asymmetries should have been inverted with orientation switches, not just eliminated. It rather seems to be re-activated only by the same types of flankers (i.e., flanker orientations) it was associated with in the previous trial. In other words, processing flankers of a particular orientation seems to induce (but not presuppose) a kind of binding between a task state and the associated stimulus features or categories. Converging evidence for both item- and category-specific stimulus-task bindings has been observed only recently in task-switching studies (Waszak, Hommel, & Allport, 2003a, 2003b).

How do these findings fit into our current understanding of flanker-congruency effects? Given the dominant interpretation of the flanker effect in terms of spotlight failure, it is important to point out that a spotlight account is insufficient to explain asymmetry effects of the sort demonstrated here. On the one hand, the assumption of an attentional "beam" wider than the target area provides a suitable account of the consistent finding that the impact of flankers varies with their distance to the target: The nearer the flanker the more likely it falls into the beam and is unintentionally processed. With additional assumptions this view may even account for the left-side bias. For some reason, the attentional spotlight may be asymmetrically extended to the left side, so that left flankers are more likely to be processed than right ones. On the other hand, however, it is difficult to see why this asymmetry should turn into symmetry or rightward extension within milliseconds, depending on the stimulus material, as seen in Experiment 2. Moreover, one would expect that spatial biases show up more strongly with near than with far flankers, which is inconsistent with both experiments. Finally, serial-search and reading studies where attentional asymmetries have been found suggest the opposite result pattern obtained here, namely a rightward or downward bias with letter material (McConkie & Rayner, 1976; Osaka & Oda, 1991; Prinz, 1983; Prinz & Kehrer, 1982; Rayner, Well, & Pollatsek, 1980).

The scanning notion is also difficult to incorporate into other simple early- or late-selection approaches. On the one hand, scanning cannot be too early because it must follow rather than precede the analysis of stimulus orientation. This analysis requires the relative localization of individual stimulus features (i.e., letter elements) and thus must be postattentional in the sense of Treisman (1988). On the other hand, scanning is unlikely to follow the complete analysis of the whole stimulus string, because this would enable normally oriented right-side letter flankers or mirrored left-side flankers to hamper performance to a certain degree. As they (often) do not, they do not seem to be fully analyzed.

As pointed out above, observations like that of orientation-specific scanning call for a more interactive selection model. Consider that, in a flanker task, stimulus selection extends over time and consists of several steps. First, upon stimulus presentation, stimuli are selected according to their match to the relevant, spatial selection criterion (Bundesen, 1990; Duncan & Humphreys, 1989). As suggested by distance effects, this readout or matching operation fails from time to time, the more so the closer (hence, more similar) the flanker is to the target. Following this (often imperfect) selection operation, selected stimuli are analyzed and identified to some degree. This may not only lead to preliminary activation of the flanker-related response (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Eriksen, Coles, Morris, & O'Hara, 1985; Smid, Mulder, & Mulder, 1990; St. James, 1990), but the properties of the selected stimuli may also retrieve certain scanning tendencies (i.e., reactivate just-used stimulus-process bindings as discussed above). Such a tendency may express itself as a tagging of stimulus positions on a spatially organized attentional control map (Humphreys & Riddoch, 1993; Mozer, 1991; Treisman, 1988; Wolfe, Cave, & Franzel, 1989; Yantis & Jones, 1991). According to Yantis and Jones (1991), one or more locations on this map, or the elements occupying these locations, can be tagged for prioritized processing. While, in a flanker task, the target element or target location should always be tagged, scanning tendencies may become effective in tagging other locations or stimulus elements as well. For instance, the classification of a stimulus string as a word-like structure may suggest tagging the leftmost part of the stimulus (cf., Calis, Teulings, & Keuss, 1983; Mozer, 1991). While this would facilitate reading the string, performance in a flanker task would be hampered, especially if the leftmost part contains an incongruent flanker.

This multiple-selection scenario follows the idea that attentional selection may not be exclusively early or late but may occur at several loci and several points in time (Allport, 1987; Humphreys & Riddoch, 1994; Miller, 1988; Pashler & Badgio, 1985; Schneider, 1995; Yantis & Johnston, 1990) and, in a sense, combines Eriksen and Eriksen's (1974) original spotlight-failure approach with Heron's (1957) scanning notion. Moreover, it provides a possible mechanism for attentional scanning that is consistent with current theoretical frameworks of visual attention. Importantly, though it attributes distance effects and asymmetries to two different selection operations (spotlight failure or incorrect template matching versus biased scanning), it also implies that both effects may not be completely independent: If, for example, the first selection step were fully successful, there would be little need for the second, so that scanning tendencies should not show up (or be rare) in the absence of spotlight leakage (or matching errors). In fact, if the distance effect is eliminated by increasing the interletter distance, the left-side bias is also absent (Hommel, 1995, Experiment 3). (The finding that a small but significant overall flanker effect remains even in this case may be due to random noise on attentional control maps, this leading to a random scan of nontarget positions now and then.)

In a sense, these considerations contradict Eriksen and Eriksen's (1974) characterization of the flanker task as a "nonsearch task". On the one hand, the subject surely knows where the target is both in absolute space and with regard to relative string position. But on the other hand, the mechanisms engaged in localizing the target seem to be the same as in a standard visual search task, and the problems they have to solve seem to be similar, too. In either task, the main problem is that nontargets sometimes receive higher priority than targets, and are thus scanned prior to them. In both tasks, the likelihood of receiving priority depends on the degree to which a stimulus element matches the selection criterion. In the flanker task, the likelihood is also determined by material-specific and stimulus-triggered scanning tendencies. Whether the same is true for standard search tasks remains to be seen. However, the finding that search is more efficient if the target appears in a location that contains a target more likely than others (Miller, 1988; Shaw & Shaw, 1977), suggest that this is indeed the case.

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