Flanker and negative flanker effects in letter identification

JEFFREY N. ROUDER and JONATHAN W. KING
University of Missouri, Columbia, Missouri

In a speeded choice reaction time task, responses to centrally presented letter targets can be altered by the identity of surrounding task-irrelevant letters (flankers). In the standard flanker effect, flankers associated with the same response as the target lead to faster and more accurate responses, whereas flankers associated with a different response lead to slower and more error-prone responses. B. A. Eriksen and C. W. Eriksen (1974, pp. 143–149) have argued that these flanker effects occur through response competition. We present data from a novel version of the Eriksen task, in which some targets and flankers consist of letter forms that are *morphed* versions of target letters. In this paradigm, flankers induce classic flanker effects on well-formed targets. But flankers induce an opposite effect, termed a *negative flanker effect* on morphed letter targets. For example, targets that are morphs between the letters "A" and "H" are more likely to be identified as an "A" when flanked by an "H." The interpretation advanced here is that there are two distinct kinds of flanker effects: contrast enhancement in perceptual processes and response competition in response selection processes.

The Eriksen flanker paradigm (B. A. Eriksen & C. W. Eriksen, 1974) has been popular in the cognition and perception literature because it allows researchers to explore the effects of context on identification. In the task, a centrally located to-be-identified letter is surrounded by a set of task-irrelevant flankers (see Figure 1). Although participants are instructed to ignore them, flankers still affect identification performance. If the target and the flanker are the same letter, the response is speeded relative to a baseline condition (see line A of the figure). If, however, the flanker and the target are assigned different responses, the response to the target is slowed relative to baseline (see line B of the figure). This effect, in which target identification is influenced by the flanker identity, is referred to as a *flanker effect*. The direction of the flanker effect is similar to that of priming: Target identification is facilitated by response-compatible flankers and inhibited by response-incompatible flankers.

As a first approximation, there are two different major interpretations of the flanker effects in the paradigm. The first interpretation is that the flanker effect results from competition at the postidentification, response selection stage. B. A. Eriksen and C. W. Eriksen (1974) provided one of the more startling demonstrations of this response competition. In their experiment, they assigned four letters to response keys: Letters "H" and "K" were assigned to one response key, and letters "S" and "C" were assigned to the other. In the critical condition, the flankers and the targets were different letters but were assigned to the same response (see line C of Figure 1). They found that the response was speeded to nearly the same degree as when the flankers and the target were the same letter. Such a result seems to indicate that the surrounding flankers influence a response selection stage rather than a perceptual identification stage. Another source of evidence for response competition comes from electrophysiological studies. The lateralized readiness potential provides an index of response preparation in the motor cortex. In the flanker paradigm, response preparation first favors the response of the flanker and only later favors the response of the target (Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). The response competition interpretation of the flanker effect has been used in clinical settings. Praamstra and his colleagues are using the magnitude of flanker effects, as well as their electrophysiological correlates, to test theories of motor preparation in patients with Parkinson's disease (Praamstra, Stegeman, Cools, & Horstink, 1998).

The second prominent interpretation of the Eriksen flanker effect is that it reflects the operation of selective attention. The main question in the selective attention literature is whether unattended items are identified or not. The late selection view is that unattended items are identified (e.g., Deutsch & Deutsch, 1963; van der Heijden, 1992), whereas the early selection view is that unattended items are not processed sufficiently for identification (e.g., Cherry, 1953; Kahneman, 1973). The behavioral result of B. A. Eriksen and C. W. Eriksen (1974), as well

Target	Response
H	
K	Left Button
S	
C	Right Button

(A) Flankers Same as Target   HHHHHHH
(B) Flankers Response Incompatible   SSSHSSS
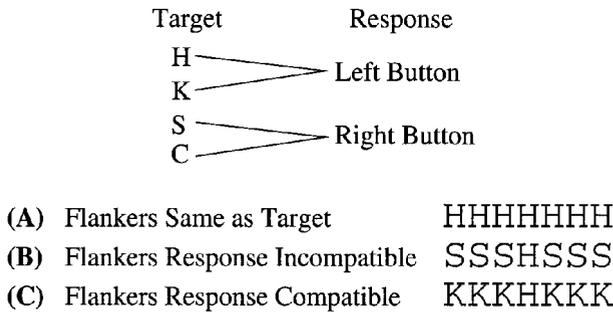**(C)** Flankers Response Compatible   KKKHKKK

Figure 1. Eriksen flanker paradigm. Letters "H" and "K" are assigned to one response, whereas letters "S" and "C" are assigned to the other. The participant identifies the middle letter. Lines A, B, and C depict critical stimuli for demonstrating response competition effects in the paradigm.

as the electrophysiological results, indicate that flanker identity is indeed processed. This result is certainly concordant with the late selection view. But it may not rule out early selection. Yantis and Johnston (1990) proposed an *attentional leakage* account in which early selection is assumed to operate in a nonoptimal fashion. If early selection is nonoptimal, some processing of the flankers occurs and affects the response. Note that whether attention selection is early and leaky or late, it is inevitable that the flanker effect comes about because flanker identity information is present at the response selection stage.

The direction of the flanker effect has been a topic of some controversy. The flanker effect has referred specifically to the case in which response-compatible flankers facilitate the target response, whereas response-incompatible flankers inhibit it. Some researchers, however, have found the opposite pattern of results in very similar paradigms. For example, Bjork and Murray (1977), Santee and Egeth (1980), Driver and Tipper, (1989), and Eimer (1998) have all found that, under certain circumstances, target identification is inhibited when targets and flankers have the same identity. Bjork and Murray (1977) and Santee and Egeth (1980) presented a display of letters and a cue. Participants were required to report the identity of the cued letter. The displays were presented briefly and subsequently masked. Accuracy served as the dependent variable. In both studies, accuracy was worse for spatially repeated letters then for unrepeated letters. For example, the second "A" in the display "AA" was more poorly identified than the "A" in "EA." Although this effect was initially attributed to feature-level inhibition (Bjork & Murray, 1977; Estes, 1972, 1974), subsequent research has challenged this account (Santee & Egeth, 1982b). Such effects are sometimes grouped with other repetition blindness effects and accounted for by type–token individuation failure theories (Kanwisher, 1991). The pattern of results in which target identification is inhibited by a flanker with the same identity is referred to here as a *negative flanker effect*. In the paradigms of Bjork and Murray (1977), Egeth and Santee (1981), and

those presented here, the flankers and the target are presented simultaneously. This aspect differs from priming and negative priming paradigms in which the prime usually precedes the target. If the flankers precede the target, the effects of the flankers could also be described as (negative) priming effects as well (e.g., Driver & Tipper, 1989; Eimer, 1998).

The presence of negative flanker effects is difficult to reconcile with response competition. In response, Eriksen and colleagues (C. W. Eriksen, 1980; C. W. Eriksen & B. A. Eriksen, 1979; C. W. Eriksen, Morris, Yeh, O'Hara, & Durst, 1981) have produced a number of experiments to explain these negative flanker effects as either guessing artifacts or artifacts of masking stimuli. Selective attention theorists have been less concerned about the direction of the flanker effect. Driver and Tipper (1989) presented flankers before they presented the target and found negative priming (a negative flanker effect). The negative priming effect was interpreted in the same manner as a flanker effect: It showed that processing of the target was affected by the identity of the flanker. The existence or lack of a flanker effect is important to the selective attention question, but the direction of the effect is less so. Conversely, selective attention theories offer little guidance in accounting for the direction of effects.

In this paper, we present a paradigm in which both flanker effects and negative flanker effects occur. The key to this paradigm is to compare performance on letter stimuli whose identities are clear (well-formed letters) with performance on stimuli whose identities are ambiguous (morphed letters). In our experiments, the morphed letters fall along a continuum between two well-formed target letters. Examples of the morphed letters used in our experiments are shown at the top of Figure 2. Flanker effects with well-formed letter targets are robust and have been replicated many times over. What
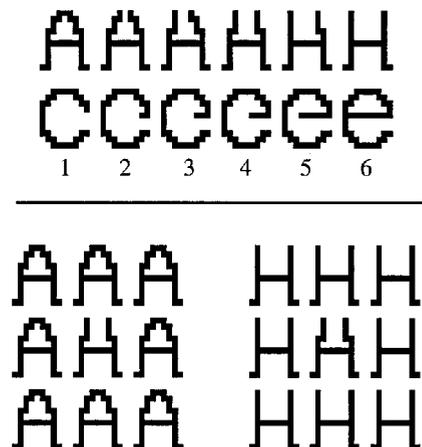

Figure 2. Top panel: Targets used in the experiments consist of well-formed and morphed letters from "A" to "H" and from "C" to "E." Bottom panel: Two examples of a morphed letter target flanked by well-formed letters. The targets are the same morphed letter but may appear different owing to a negative flanker effect.

is unknown are the effects of flankers on morphed-letter targets. Morphed letters have been used previously to explore letter identification models, as well as the interactions between word-level information and letter-level information (e.g., Massaro, 1988; Massaro & Hary, 1986; Oden, 1979; Rueckl & Oden, 1986). One finding in this literature is that morphed stimuli are affected by a word context in a manner similar to that for well-formed letters. For example, the word context "WIT_" strongly suggests that the last letter is an "H" rather than an "A." A morph between "A" and "H," placed in this context, would be more likely to be identified as an "H," relative to baseline. On the basis of these results, it seems reasonable that the Eriksen flanker context should affect morphed and well-formed letters similarly; that is, there should be a classic flanker effect.

The bottom of Figure 2 shows two examples of a morphed letter target (between A and H) surrounded by an "A" and an "H," respectively. Our subjective observation is that of a contrast effect. The morphed letter surrounded by "H" appears more like an "A," whereas the morphed letter surrounded by "A" appears more like an "H." This observation is well supported by our present experiments. This negative flanker effect occurs in a "true" Eriksen flanker paradigm: (1) The target is fixed and central, (2) the flankers and the targets are presented simultaneously, and (3) there is no subsequent mask. Hence, the presence of negative flanker effects for some stimuli, but not for others, stands as a strong challenge to the hypothesis that flankers affect only the response selection stage through response competition. In fact, we conclude that flanking information in displays have perceptual as well as postperceptual effects on target identification and that these effects are in opposite directions.

The experiments presented were originally conducted under the premise that there would be a flanker effect for all targets, whether they were well-formed or morphed letters. Our original intent was to explore the processes involved in flanker effects by applying the diffusion model of Ratcliff and colleagues (Ratcliff & Rouder, 1998; Ratcliff, Van Zandt, & McKoon, 1999) to the Eriksen flanker paradigm. The diffusion model provides a theoretical means of assessing differences in encoding bias, response bias, and sensitivity across different conditions. In order to apply the diffusion model, it is helpful to have several levels of response accuracy. We simply used the morphed letters as a means by which to vary accuracy. But the following findings with both flanker and negative flanker effects were so rich that they caused us to abandon the original diffusion modeling effort and reconsider the locus of flanker effects.

EXPERIMENT 1

Method

Participants. Twenty-two University of Missouri undergraduates served as participants as part of an introductory course requirement. The data from 2 participants were discarded because they responded

to the flanker identity instead of the target identity. The data from the remaining 20 participants were included in the analyses.

Stimuli and Design. Target identity and flanker identity served as the main independent variables for Experiment 1. The targets for Experiment 1 were the six letters morphed from "A" to "H" that are displayed in the top row of Figure 2. The flankers were "A," "H," or the third morphed letter (labeled "3" in Figure 2). These six targets and three flankers were crossed to produce 18 stimuli. Both factors were repeated within participants. Each stimulus was a 3 × 3 array of letters, with the target being the middle letter and the flankers being the remaining eight letters. Stimuli were drawn as white segments against a black background and subtended about 1.7° of arc.

Apparatus. The stimuli were displayed on PCs with the MovieLib[1] library of Turbo C routines for DOS. The monitors were 17-in. Dell P780s driven at 60 Hz. The participants were tested individually in well-lit cubicles.

Procedure. An experimental trial consisted of the following three events: First, the screen was blank during a 1-sec foreperiod; second, after the foreperiod, the stimulus was presented for 100 msec; and third, the stimulus was replaced with a blank screen until the participant responded. The ensuing response marked the end of the current trial and the start of the next one. A block consisted of 108 such trials, and the participants observed 10 blocks in an experimental session. Sessions lasted about 35 min. The participants were encouraged to take breaks in between blocks. The first 50 trials of the session and the 1st trial of each block were excluded from the analysis as practice trials. The participants were shown a number of stimuli before the experiment started including those with morphed letter targets and morphed letter flankers. They were instructed to respond with the left response key if the target was an "A" and with the right response key if the target was an "H." For morphed letter targets, the participants were instructed to respond with the left key if the target was more similar to an "A" than to an "H" and vice versa. The left and right response keys were the "z" and the "/" keys on a computer keyboard, respectively. The participants received no feedback about their responses during the course of the session.

Results

Responses with times less than 200 msec and greater than 3 sec were excluded from the analyses. Such responses constituted less than one half of one percent of the total. Figure 3 shows response proportion and response time (RT) performance measures. The graphs are organized so that the target type is on the abscissa and the performance measure is on the ordinate. Each of the three lines corresponds to a different flanker condition (solid thick lines indicate that "A" letters were the flankers, dashed thick lines indicate that "H" letters were the flanker, and dashed thin lines indicate that the third morphed letter between "A" and "H" was the flanker).

The top panel shows the proportion of times the participant identified the target as an "A" or more similar to an "A" than to an "H." As can be expected, participants responded "A" less frequently as the target was manipulated from "A" to "H." The most intriguing aspect of the data, however, is the interaction between flanker and target type. When the target was a well-formed letter (either "A" or "H"), there were small flanker effects. For example, if the flanker was an "A," there was a higher proportion of "A" responses. However, the reverse pattern held for morphed stimuli; there were negative flanker effects. The proportion of "A" responses decreased when "A"
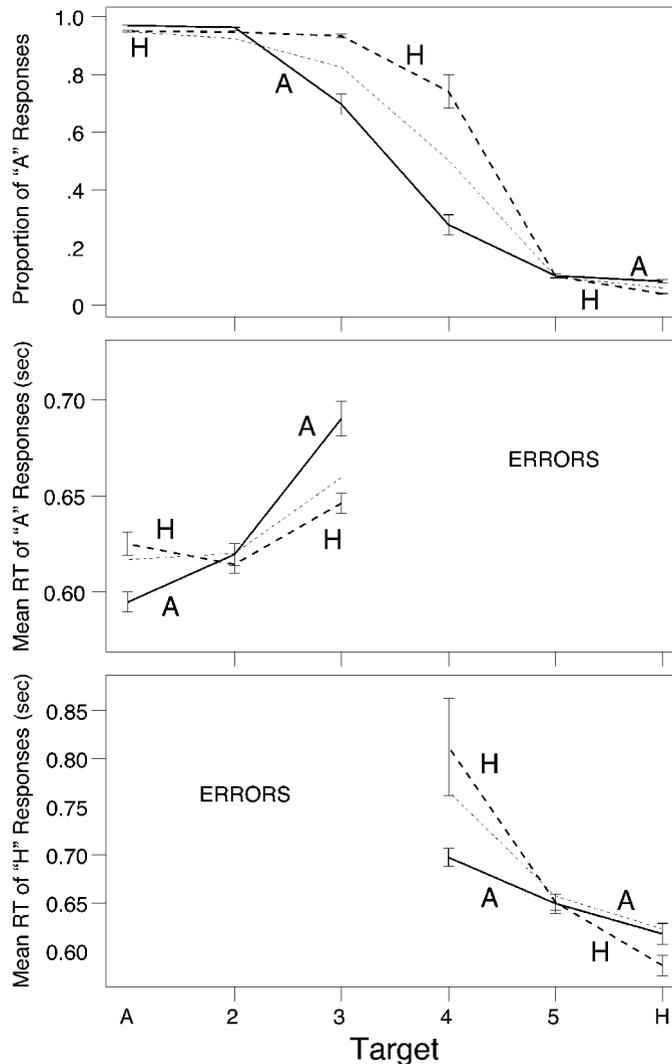
Figure 3. Results from Experiment 1. The top panel shows response proportions; the middle and bottom panels show response times (RTs) for correct responses. Thick solid lines indicate that "A" letters were the flankers, thick dashed lines indicate that "H" was the flanker, and thin dotted lines indicate that the morphed letter 3 was the flanker. Error bars denote standard errors. For response proportions, standard error reflects variability across both individuals and conditions. For RT, the standard errors reflect variability due to condition alone. Error bars are not included for the case in which the third morph served as the flanker (thin dotted line) for clarity of presentation. These error bars are comparable to those displayed for the other two flanker conditions.

was the flanker. As can be seen in the top panel, the effect was exceedingly large for the third and fourth morphed letters. The reason the error bars are large is that some participants consistently classified the morphed letter as either "A" or "H." A repeated measures analysis of variance (ANOVA) revealed significant main effects of target type [$F(5,95) = 385.7$, $MS_e = 0.026$, $p < .05$] and flanker [$F(2,38) = 38.4$, $MS_e = 0.008$, $p < .05$], as well as

a significant interaction [$F(10,190) = 41.2$, $MS_e = 0.005$, $p < .05$]. The differential effects of flankers on well-formed and morphed letters were statistically reliable.

The RT data are also plotted, and these show a similar pattern. There are two RT plots; the middle panel shows RTs for "A" responses, and the bottom panel shows RTs for "H" responses. The panels show RTs for "correct" responses only; that is, the middle panel, shows RTs for

the "A" response to "A" targets and morphed letters 2 and 3. Likewise, the bottom panel shows RTs for the "H" response to "H" targets and morphed letters 4 and 5. The standard errors associated with the error RTs are quite large, and these data add nothing systematic to the analysis.

In both panels, there is a sizable flanker effect for the well-formed letter targets. In this case, RT was slowed when the flanker was associated with the opposite response, as compared with when the flanker was associated with the same response. But the effect was reversed (i.e., there was a negative flanker effect) for morphed letters 3 and 4. For these targets, RT was speeded when the flanker was associated with the opposite response, as compared with when the flanker was associated with the same response. A repeated measures ANOVA for the middle panel revealed a significant effect of target [$F(2,38) = 72.9$, $MS_e = 0.0007$, $p < .05$] but an insignificant main effect of flanker [$F(2,38) = 0.564$, $MS_e = 0.001$]. Most important, the interaction between target and flanker was significant [$F(4,76) = 8.82$, $MS_e = 0.0008$, $p < .05$]. The same analysis on the bottom panel reveals the same pattern of significance: a significant main effect of target [$F(2,38) = 27.1$, $MS_e = 0.013$, $p < .05$], an insignificant main effect of flanker [$F(2,38) = 1.76$, $MS_e = 0.009$], but a significant target $\times$ flanker interaction [$F(4,76) = 4.27$, $MS_e = 0.007$, $p < .05$].

Note that for the top panel, the error bars reflect variability due to individuals, as well as unaccounted sources of variability. But for the error bars in the middle and bottom panels, the variability due to individuals was removed (see Loftus & Masson, 1994). For technical reasons that are beyond the scope of the present paper, it is difficult to remove variability due to individuals from error bars on full-range psychometric data. Fortunately, the repeated measures ANOVA effectively models variability due to individuals for both response proportion and RT cases.

Discussion

Our results with stimuli taken from an "A" to "H" letter continuum provided evidence for both flanker and negative flanker effects at the same time. There were flanker effects for well-formed letter targets but negative flanker effects for morphed letter targets. Although the flanker effects were not large in response proportion (possibly owing to floor and ceiling effects), they were quite large in RT. The negative flanker effects, however, were large in both RT and response proportion. Although we felt that these results were compelling, the fact that they were unanticipated suggested that we should seek an independent replication, which was the purpose of Experiment 2.

EXPERIMENT 2

Experiment 1 yielded large negative flanker effects with specific morphed letter stimuli, and one could wonder whether it was their hypothesized in-between-categories property or some other irrelevant factor that was responsible for those results. Fortunately, we could investigate these issues with a distinct morph continuum that arguably manipulated a different kind of letter feature. Figure 2 shows a letter continuum between the lower case letters "c" and "e" that includes four different in-between forms; these stimuli served as the targets in Experiment 2. All other aspects of the experiment, with the exception of the participants, were identical to those in Experiment 1. The participants were 22 undergraduate students who served in order to fulfill an introductory psychology course requirement.

Results and Discussion

Figure 4 shows the response proportion and RT results for Experiment 2. The results follow the same general pattern as that observed in Experiment 1. In particular, if the target was an unambiguous well-formed letter, there were significant flanker effects seen in both response proportion and RT. For example, the target "c" was responded to more quickly and more accurately if the flankers were "c" than if they were "e." But if the target was a morphed letter, there were large negative flanker effects in both response proportion and RT. For example, the third morphed target was identified as a "c" almost twice as often as an "e" and was identified more than 100 msec faster if the flankers were the letter "e" than if they were the letter "c." Separate repeated measures ANOVAs were done for each panel. The results are shown in Table 1. The significant interaction between context and flanker in all three panels indicates that the qualitatively different effects of the context on well-formed letters and morphs were statistically reliable.

EXPERIMENT 3

The results from Experiments 1 and 2 were consistent; there are flanker effects for well-formed targets but negative flanker effects for morphed targets. Experiment 3 was designed to test the hypothesis that flanker and negative flanker effects have different loci. Negative flanker

Table 1
F Tests for Experiment 2

Test	Result
Proportion of "C" Responses	
Main effect: target	$F(5,105) = 278.00$, $MS_e = 0.0370$
Main effect: flanker	$F(2,42) = 31.80$, $MS_e = 0.00450$
Interaction: target $\times$ flanker	$F(10,210) = 19.10$, $MS_e = 0.0036$
Response Time of "C" Responses	
Main effect: target	$F(2,42) = 33.10$, $MS_e = 0.0100$
Main effect: flanker	$F(2,42) = 2.27$, $MS_e = 0.0039$
Interaction: target $\times$ flanker	$F(4,84) = 7.41$, $MS_e = 0.0042$
Response Time of "E" Responses	
Main effect: target	$F(2,42) = 42.30$, $MS_e = 0.0040$
Main effect: flanker	$F(2,42) = 9.66$, $MS_e = 0.0017$
Interaction: target $\times$ flanker	$F(4,84) = 10.50$, $MS_e = 0.0017$

Note— All tests other than that in italics are significant at the $p < .05$ level.
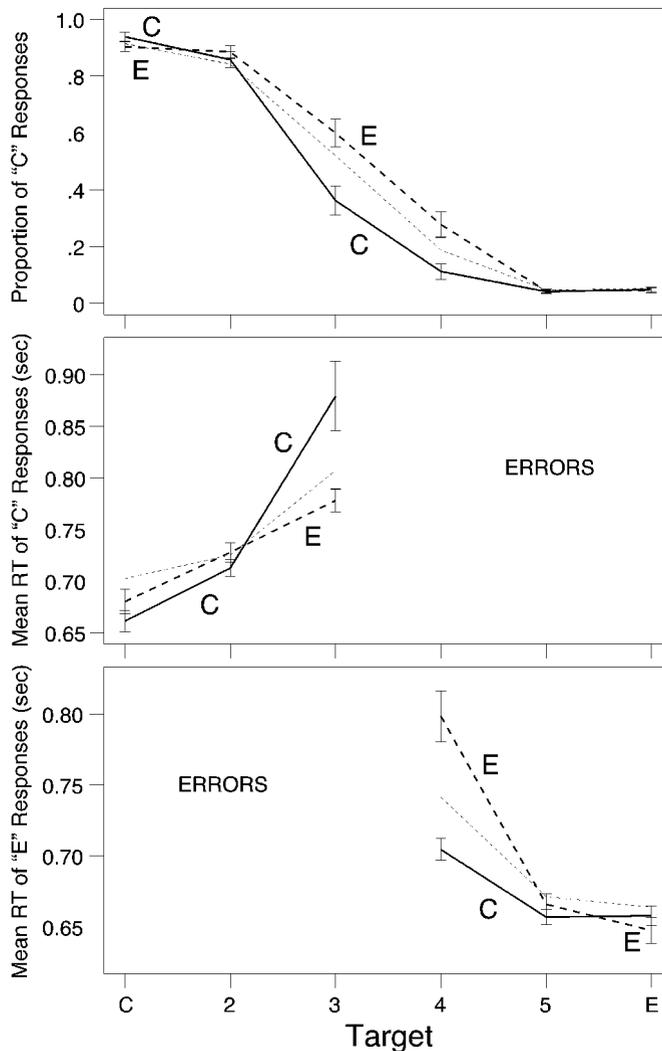
Figure 4. Results from Experiment 2. The top panel shows response proportions; the middle and bottom panels show correct response times (RTs). Thick solid lines indicate that "c" letters were the flankers, thick dashed lines indicate that "e" was the flanker, and thin dotted lines indicate that the third morph was the flanker. Error bars denote standard errors calculated in the same way as in Experiment 1.

effects may result from contrast in perceptual processes occurring before letter identification, whereas flanker effects may result from response competition. We followed the original strategy of B. A. Eriksen and C. W. Eriksen (1974), who assigned two letters to each response. The participants in Experiment 3 were shown 8 of the 12 targets in Figure 2 and were instructed to assign targets that were more similar to an "A" or a "c" to the left response and those more similar to an "H" or an "e" to the right response. It is helpful to define a *continuum* of targets as two letters and their in-between morphed letters. For example, all of the targets in the top row in Figure 2 form one continuum, and all of the targets in the bottom row form another continuum. B. A. Eriksen and

C. W. Eriksen found that performance was enhanced when the flankers and the target were different well-formed letters that were associated with the same response. This result constitutes behavioral evidence that flanker effects occur in response selection, rather than in perceptual processes. In Experiment 3, we investigated whether negative flanker effects would occur when the target and the flankers were from different continua. If the locus of the negative flanker effect is due to perceptual contrast, there should be no negative flanker effects when the target and the flanker are from different continua. But if the negative flanker effect results from response selection processes, it should occur when the target and the flankers are from different continua.

Method

Participants. Thirty-four University of Missouri undergraduates served as participants to fulfill an introductory course requirement.

Stimuli and Design. The two well-formed letters and the third and the fourth morphed letters from each continuum served as targets (a total of eight targets). The same eight letters also served as flankers, and these target and flanker conditions were crossed to produce a total of 64 different stimuli. All 64 stimuli were presented in a within-block design. Stimulus rendering was the same as that in Experiment 1.

Procedure. The procedure was identical to that in Experiment 1, with the following exceptions. First, the participants were given an extended practice block of 80 trials in which the stimulus was presented for 1 sec. In the practice block, the only targets were well-formed letters, and the participants received auditory feedback after their responses. The goal in the practice block was to give the participants the opportunity to learn the response assignments. After this practice block, stimulus duration was reduced to 100 msec, and the auditory feedback was removed. This presentation procedure was exactly the same as that in the previous experiments. The practice block, the first 50 trials of the second block and the first trial of each additional block were excluded from the following data analyses.

Results and Discussion

Responses with times less than 200 msec and greater than 3 sec were excluded from the analyses. Such responses constituted 1.6% of the total. Figure 5 has four panels, and each panel shows response proportions for various flanker and target combinations. As before, the abscissa is the target, and the ordinate is the response proportion (the proportion of "A" or "c" responses). The lines indicate flanker conditions. The solid line indicates that the flanker was either an "A" or a "c," the dashed line indicates that the flanker was either an "H" or an "e," and the thin dotted line indicates that the flanker was a morphed letter. We averaged over the third and fourth morphed flankers, since the resulting data were fairly similar. Panel A depicts the case in which the targets and

the flankers are both from the A–H continuum. Because the targets and the flankers were from the same continuum, we term these conditions as *matched*. As can be seen, a negative flanker effect is evident for the morphed targets (e.g., the third morphed letter is responded to as an "A" more often when it is surrounded by an "H" than when surrounded by an "A"). Panel B shows the other matched set of conditions; the target and the flankers are both from the c–e continuum. Again, the predominant finding is a negative flanker effect for morphed letter targets. But the opposite finding holds for mismatched conditions. In panel C, the targets are from the A–H continuum, whereas the flankers are from the c–e continuum. In these data, there are flanker effects. That is, the third morphed letter between A and H is more likely to be identified as an "A" when it is surrounded by "c" than when it is surrounded by "e." The data from the other mismatch condition (panel D, targets are from the c–e continuum, flankers are from the A–H continuum) also show similar flanker effects.

A repeated measures ANOVA was performed with four factors: target-continuum (two levels, A–H, c–e; labeled "T-continuum" in Table 2), target type (four levels, labeled "Target" in Table 2), flanker type (two levels, A/c or e/H, labeled "Flanker" in Table 2), and flanker continuum (two levels, matches target or mismatches target; labeled "F-continuum" in Table 2). Although there are 15 tests in the full factorial design, the three-way target × flanker × flanker continuum interaction is theoretically most important. This interaction tests the trend observed that if the target and the flanker matched, there was a negative flanker effect for morphed targets, but if the target and the flanker mismatched, there was a (positive) flanker effect for morphed targets. This interaction was significant [$F(9,297) = 8.32, MS_e = 0.0112, p < .05$].
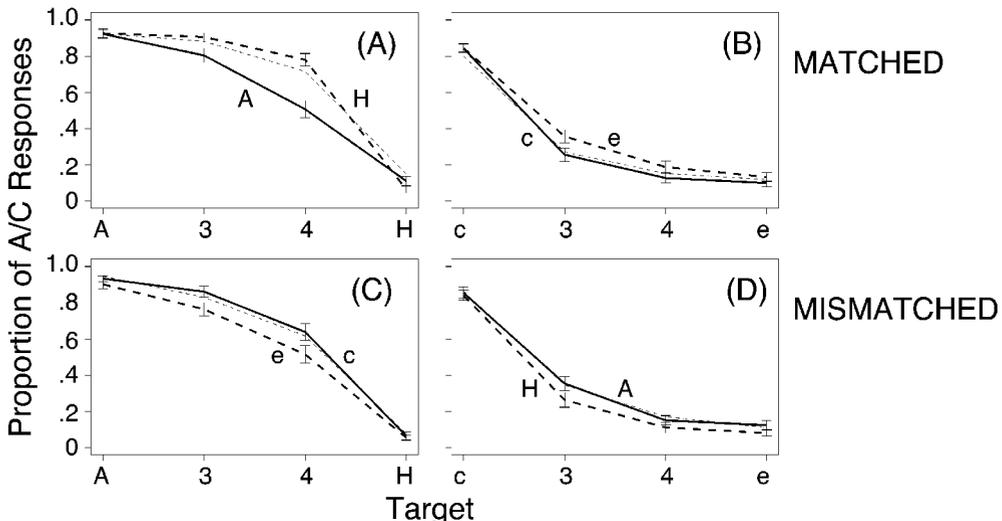

Figure 5. Response proportion results from Experiment 3. Solid thick lines indicate that letters "A" or "c" were flankers, dashed thick lines indicate that letters "H" or "e" were flankers, and dashed thin lines indicate that morphed letters were flankers. Error bars denote standard errors, which reflect variability across both individuals and conditions.

Table 2
F Tests for Response Probability in Experiment 3

Test	Result
Main Effects	
Target	$F(3,99) = 359.50$
Flanker	$F(3,99) = 5.54$
T-continuum	$F(1,33) = 86.40$
F-continuum	$F(1,33) = 9.44$
Two-Way Interactions	
Target × flanker	$F(9,297) = 2.70$
Target × T-continuum	$F(3,99) = 76.00$
Target × F-continuum	$F(3,99) = 6.65$
Flanker × T-continuum	$F(3,99) = 6.46$
Flanker × F-continuum	$F(3,99) = 24.40$
T-continuum × F-continuum	$F(1,33) = 33.00$
Three-Way Interactions	
Target × flanker × T-continuum	$F(9,297) = 1.29$
Target × flanker × F-continuum	$F(9,297) = 8.32$
Target × T-continuum × F-continuum	$F(3,99) = 2.17$
Flanker × T-continuum × F-continuum	$F(3,99) = 4.23$
Four-Way Interaction	
Target × flanker × T-continuum × F-continuum	$F(9,297) = 3.92$

Note— All tests other than those in italics are significant at the $p < .05$ level.

Table 2 shows the results from all 15 tests. Almost all of these tests were significant. *Nonsignificant tests are italicized.* The four-way interaction was significant, indicating that the critical three-way interaction varied with the target continuum. The differing effects of matching and mismatching flankers was larger when the target was on the A–H continuum than when it was on the c–e continuum. The reason for this is not readily apparent.

The RTs for Experiment 3 can be seen in Figure 6. The figure has eight panels, which are clustered into four groups of pairs of panels. The left-hand member of each pair shows the correct response RTs for "A" and "c" responses, whereas the right-hand member of each pair shows the correct response RTs for "H" and "e" responses. The top row of panels denotes data from matched conditions, whereas the bottom row of panels denotes data from mismatched conditions. As can be seen, RT effects were attenuated in Experiment 3. Repeated measure analyses were performed separately on correct RTs. There were some significant effects of the 30 statistical tests, but the key three-way target × flanker × flanker continuum interaction was insignificant for both "A/c" responses [$F(3,95) = 1.20$, $MS_e = 0.019$] and "e/H" responses [$F(3,95) = 0.567$, $MS_e = 0.016$]. On the whole, there were few systematic differences in RTs that are of theoretical interest. These RT results are a departure from the previous ones, in which large flanker and negative flanker effects were obtained. The cause for the discrepancy is not immediately apparent.

GENERAL DISCUSSION

In this paper, we have demonstrated that both flanker and negative flanker effects can occur in the Eriksen flanker paradigm. Negative flanker effects occur when the target is a morphed letter, whereas flanker effects occur when the target is a well-formed letter. Furthermore, the flanker and the negative flanker effects most likely have different loci, with negative flanker effects resulting from perceptual processes and flanker effects resulting from response competition.
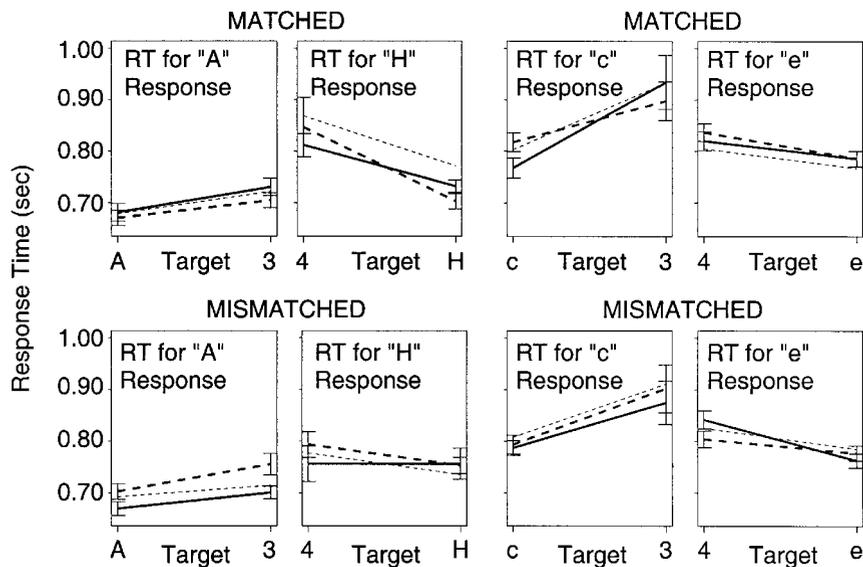

Figure 6. Response time (RT) results from Experiment 3. Thick solid lines indicate that "c" letters were the flankers, thick dashed lines indicate that "e" letters were the flankers, and thin dotted lines indicate that morphed letters were the flankers. Error bars denote standard errors, which reflect variability to condition alone.

Santee and Egeth (1982a) promoted a theory of two loci for the effect of flankers. Flankers induce a contrast-type effect in perceptual stages as well as in response competition. Such a theory is highly consistent with the results reported here. Santee and Egeth (1982a) proposed that contrast effects are more pronounced when the letter targets are followed by a pattern mask. In these cases, the perceptual effects overwhelm the response competition effects, yielding a net negative flanker effect. However, when the stimuli are readily and accurately recognized, the response competition effects overwhelm the perceptual effects, yielding a net flanker effect. We advance a similar account, depicted in Figure 7. The flanker effect from response competition is of moderate size and is assumed to be constant across a letter continuum. The contrast effect at the perceptual stage varies in size across a letter continuum. When perception is difficult, because target letters are either morphed or degraded through pattern masking, the contrast effect is more pronounced. This yields a net negative flanker effect. But when perception is easy (i.e., when the target letter is well formed and presented without a pattern mask), the contrast effect is rather small, yielding a net flanker effect.

The conceptualization in Figure 7 brings forth a new puzzle: Why is there such a strong negative flanker effect with morphed stimuli, and not with well-formed letters? This puzzle cannot be solved with the notion of feature-specific lateral inhibition. In feature-specific lateral inhibition (e.g., Bjork & Murray, 1977; Estes, 1972, 1974), the features in one letter inhibit the activation of the corresponding features in other letters. Such a theory was useful in explaining why the letter "A" in a rapidly presented and subsequently masked presentation of the string "EA" was better perceived than the letter "A" in the string "AA." However, such a theory fails to explain the lack of negative flanker effects with well-formed letters, as was shown here. Although Santee and Egeth (1980) initially argued in favor of feature-specific lateral inhibition, they (Egeth & Santee, 1981) later argued that the inhibition may have a substantial semantic or cognitive component. For example, they showed that a lowercase "a" can inhibit an uppercase "A."

Another explanation of negative flanker effects is the token individuation hypothesis of Kanwisher (1987). Kanwisher's main goal in the 1987 article was both to document the repetition blindness phenomenon and to provide an explanation of both repetition priming and repetition blindness. According to the token individuation hypothesis, information about targets is kept at two levels: the *type level* and the *token level*. Type-level information represents the general activation of an item independent of the stimulus event. Token-level information represents a binding of a concept to particular markers in the stimulus event. Kanwisher theorizes two loci for repetition effects. First, repetition increases type-level activation for the repeated item. But repetition also decreases the activation of the token in the second pre-

sentation, as compared with that in the first. This decrease in token-level activation for the second token makes it difficult to detect repetitions in rapidly presented visual streams. The increase in type-level activation is responsible for repetition priming in tasks in which the participants are encouraged to use type-level information (e.g., identify the last element of a visual stream, state whether or not a particular target was present in a display).

Kanwisher (1991) assumed that Bjork and Murray's (1977) negative flanker effects are an instance of repetition blindness and can be explained by the token individuation hypothesis. Accordingly, responses must be based on token-level information. The basic idea is that the binding of the location information to the target letter is degraded if the letters are repeated. For example, consider the case in which the participants must identify the second letter of the string "AA" versus the case in which they must identify the second letter of the string "EA." According to the token individuation hypothesis, performance is superior in the "EA" case because the "A" token—that is, the binding of "A" to the second location—is unaffected by the presentation of "E" in "EA" but is degraded by the presentation of the first "A" in "AA." A different aspect of the theory may even be useful in explaining flanker effects when they occur. Flanker effects may result from the influence of type-level information from the flankers. For this explanation to be consistent with our results, it must be assumed that type-level information is used when the target is well formed and not masked but that token-level information is used when the target is morphed or masked. We are not certain about the rationale or mechanisms that would allow for such a differential use of type- and token-level information.

Perhaps the simplest route to an explanation of the present results is to postulate that morphed letters are perceived somewhat differently from well-formed letters. Previous work from Massaro, Oden, and colleagues has treated the perception of morphed letters as following the same basic rules and structures as the perception
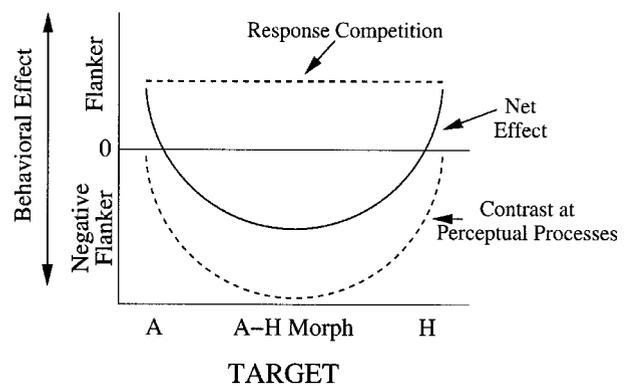

Figure 7. The flanker effect at the response selection stage is constant. The negative flanker effect at the perceptual stages is a function of the difficulty of identification.

of well-formed letters (Massaro, 1988; Massaro & Hary, 1986; Oden, 1979; Rueckl & Oden, 1986). In light of the present evidence, we take a different approach: Perceiving morphed letters involves an extra processing stage. The notion of an additional stage for making difficult decisions is not novel. Balota and Chumbley (1984), for example, postulated additional stages in the determination of the lexical status of a string when the decision is difficult—namely, when the string is a low-frequency word or a pronounceable, orthographically regular nonword. In these additional stages, participants engage in a lexical recheck of the string.

In our proposal, perception of well-formed targets is relatively straightforward and is done fairly quickly and automatically. The evidence for this facility can be seen in the high accuracy in responses to well-formed letters. In this mode, target perception proceeds with little effect from the flankers. Although perception is uninfluenced by the flankers, the response is still influenced by response competition. But when presented with a morphed or a masked letter, the recognition system does not initially register sufficient activation for any identification. This lack of sufficient activation results in the recognition system's entering a different mode. In this mode, the recognition system searches for additional sources of information. In the present paradigm, that additional source of information is the flanker identity. The visual system is able to compare the percept of the target to that of the flankers. Given a mismatch between percepts, the recognition system is likely to conclude that the target differs from the flankers. This, in turn, produces an increased probability of the opposite response to the flanker—a negative flanker effect. We offer this theory as a post hoc guideline for uniting both our results and previous results.

The relevance of the negative flanker effect with morphed stimuli becomes more striking when compared with other empirical findings with morphed letters. Massaro, Oden, and colleagues have been systematically exploring letter recognition with similarly morphed stimuli (Massaro, 1988; Massaro & Hary, 1986; Oden, 1979; Rueckl & Oden, 1986). When a morphed letter is surrounded by a word context that is more consistent with one of its interpretations, the morphed letter is more likely to be identified as the consistent interpretation. For example, a morphed letter between "c" and "e" is more likely to be identified as an "e" when embedded by the context "_dit," relative to baseline. Likewise the same target is more likely to be identified as a "c" when embedded in the context "_oin," relative to baseline. These are clear examples of flanker effects with morphed letters: The word context plays the role of flanking information, and the concordant response is favored. When compared with these results, our negative flanker results with morphed letters indicate that the nature of the flanking information is crucial.

Our conjecture is that the visual system uses flanking information as a second source of information when discrimination is difficult. This conjecture is similar in spirit to Massaro and Oden's (1979) fuzzy logical model of perception. One aspect of that model is that a second source of information has a greater effect in mediating recognition when the primary source is ambiguous. To unite the opposing results of a flanker effect in word contexts and negative flanker in the present flanker paradigms, we propose an explanation based on Gestalt principles (Wertheimer, 2000). When the participants are presented with displays in the word context effect experiments, they attempt to read the string as unitized words. In the course of reading the strings as a unitized word, the participants' perception of the morphed letter is subject to (positive) flanker effects of word-level information. Yet, in our Eriksen flanker displays, there is no evident word form. The participants are not attempting to read the letters in a unitized fashion, but they are focusing on the individual letters themselves. In this case, the goal is to differentiate the letters from one another. Therefore, when the visual system incorporates the flanking information to identify a single item, it does so in a contrastive mode, producing a negative flanker effect. The crucial difference between word context and flanker paradigms is that in the former, the paradigm is conducive to unitizing the stimulus into a whole percept (the word), leading to flanker effects. In the latter, the stimuli are conducive to individuation, leading to negative flanker effects.

Our conjectures about the mechanisms of flanker and negative flanker effects are necessarily post hoc. Fortunately, they yield plausible predictions. One fertile ground for testing may be the rapid serial visual presentation (RSVP) paradigm (Potter & Levy, 1969). In this paradigm, both repetition priming and repetition blindness are known to occur. As has been noted by several authors, the repetition priming/blindness tasks may be construed as a generalized flanker task in which the flankers occur in time rather than in space. According to our approach, the difficulty of the identification task has ramifications for whether there is repetition blindness (a negative flanker effect) or repetition priming (a flanker effect). Consider the task in which the participant has to identify the last element of an RSVP display. We predict that the identification of a well-formed letter target will be facilitated by a previous repetition. This facilitation arises from response competition. Such an explanation is also consistent with the biased-processing interpretation of priming in implicit tasks, offered by Ratcliff and McKoon (1997). Indeed, Kanwisher (1987, Experiment 3) found facilitation in this exact task. Our conjecture also predicts that there will be a negative priming effect on morphed letter targets from previous exposure of a similar well-formed letter. For example, if the letter A is part of an RSVP display that is terminated with an A–H morphed letter, that morphed letter is more likely to be seen as an H, relative to the appropriate baseline.

RSVP experiments may be helpful in elucidating the second part of our conjecture concerning the role of

word-level information. If an RSVP display forms a valid word, the word implied by the previous letters should have an assimilative effect on a trailing morphed letter. For example, consider the RSVP display of "DAT*" in which the * is a A–H morphed letter. The first three letters are consistent with the word "DATA." If all of the RSVP displays in a block of trials readily admit word completions, we hypothesize that participants attempt to unitize the RSVP displays into words. In this case, we predict flanker effects; the A–H morph is more likely to be identified as "A" than it would be in a baseline condition. But, consider the RSVP display "XAT*." If this RSVP display is presented in a block in which none of the displays admits word completions, participants may not attempt to unitize the display. In this case, the letter "A" may induce a contrast effect on the trailing morphed letter. If our conjectures prove to be inaccurate, the present finding of differential flanker and contrast effects with morphed and well-formed letters in the Eriksen flanker paradigm raises interesting questions about the roles of figure and ground in letter recognition.

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NOTE

1. The MovieLib library is freely available at taxa.psyc.missouri.edu/~jeff/movielib.html.