*Psychonomic Bulletin & Review*
*2008, 15 (2), 385-389*
*doi: 10.3758/PBR.15.2.385*

# Feature integration without visual attention: Evidence from the correlated flankers task

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It is widely assumed that the separable features of visual objects, such as their colors and shapes, require attention to be integrated. However, the evidence in favor of this claim comes from experiments in which the colors and shapes of objects would have to be integrated and then also subjected to an arbitrary, instruction-based, stimulus–response (S–R) translation in order to have an observable effect. This raises the possibility that attention is not required for feature integration, per se, but is only required when color–shape conjunctions must undergo an arbitrary S–R translation. The present study conducted a more specific test and found strong evidence in favor of feature integration in the absence of attention. The implications of these results are discussed.

There is considerable evidence that the surface features of visual objects, such as their colors and shapes, are initially represented separately (see Treisman, 1988). It is further asserted that visual attention is required to integrate these separable features (e.g., Treisman & Gelade, 1980). Much of the evidence supporting the critical role of attention in feature integration comes from work examining visual search (see Quinlan, 2003). The most widely cited models of this task, Feature Integration Theory (e.g., Treisman, 1988) and Guided Search (e.g., Wolfe, 1998), can be summarized as involving two processing stages. The second stage is where the separable features of visual items are integrated; this stage is argued to be strictly serial and to directly involve visual attention.

The first of these two claims has already been questioned in the literature (e.g., Mordkoff, Yantis, & Egeth, 1990; Pashler, 1987) and some models now include parallel processing of a limited number of color–shape conjunctions (e.g., Bundesen, 1990; Grossberg, Mingolla, & Todorović, 1989). There are also several demonstrations of apparently parallel processing when one of the features employed to create the conjunctions involves some type of motion (e.g., Nakayama & Silverman, 1986) or stereoscopic disparity (e.g., Enns & Rensink, 1990).

In contrast, there is very little evidence against the idea that attention is necessary for the integration of separable features. The clearest piece of contrary data is the finding of conjunction-based visual aftereffects; these phenomena can be found even when the adapting stimulus is not attended (e.g., Houck & Hoffman, 1986). Less directly, there is also evidence in favor of the early registration of color-orientation conjunctions from tasks involving rapidly alternating, flickering displays (Holcombe & Cavanagh, 2001). Of course, these experiments are radically different from those requiring visual search; and yet, this difference in paradigms should not be used to brush one set of data aside. Rather, it could be used to raise questions, suggest new models, or motivate novel experiments.

One such question is whether the data that are usually taken as support for the requirement of visual attention in conjunction-based tasks might be explained in some other manner. For example, maybe attention is not required to integrate the separable features of visual objects; maybe it is needed only to select and produce the task-related, overt response. Or, in more mechanistic terms, maybe representations of color–shape conjunctions are formed without attention (which would explain the aftereffects), but attention is necessary for the same items to be associated with particular responses using the arbitrary stimulus–response (S–R) mapping of a typical experiment.

To test this alternative, a task is needed under which (1) the influences of unattended conjunctions can be observed; (2) overt responses to these items are not required; and (3) the unattended conjunctions need not undergo any instruction-based S–R translation in order to have an effect. At the same time, rather than relying on an aftereffect, it would be greatly preferable if this task were closer to those typical of laboratory studies of information processing. Fortunately, with some modification, such a task is available—namely, the *correlated flankers task* (Miller, 1987), a variant of the *standard flankers task* (Eriksen & Eriksen, 1974).

In general, a flankers task requires selective attention, because to-be-ignored items (i.e., the flankers) are presented in the same display as the task-relevant target. In the original, standard version of the task, the flankers are stimuli linked with responses via the instructions. For example, if the stimuli assigned to the left-hand response (when presented in the to-be-attended location) are the letters *A* and *B*, and the stimuli assigned to the right-hand response are the letters *Y* and *Z*, a standard flankers task

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would often involve displays with either *A*s, *B*s, *Y*s or *Z*s in the to-be-ignored locations. The standard flanker effect is the difference in performance between trials on which the flankers are associated with the same response as the target (known as "congruent" trials) and those on which the flankers are associated with the opposite response as the target ("incongruent" trials).

In the correlated version of the flankers task, the to-be-ignored items are not linked with either response via the instructions; instead, these to-be-ignored items are associated with certain responses via planned imbalances in the trial frequencies. For example, assuming again that the stimuli assigned to the left and right responses are *A*, *B*, *Y*, and *Z*, if the letter *M* appeared in the to-be-ignored locations more often on left- than on right-response trials, this stimulus would become a correlated flanker positively associated with the left response and negatively associated with the right. Once established, these associations can act as "short cuts" between stimulus representations and response representations, skipping all central processes such as S–R translation. In this way, they do not depend on either instructed relationships or even awareness of the correlations to have their effects (see Miller, 1987).

## GENERAL METHOD

In all of the reported experiments, two targets were assigned to the left-hand response and two to the right. The targets were color–shape conjunctions, designed so that both features would have to be identified in order to determine which response was required. For example, if the colors were *red* and *green*, and the shapes were *square* and *diamond*, the two targets assigned to one response would be *red square* and *green diamond*, whereas the alternative two targets would be *red diamond* and *green square*. The task was always to respond to the item presented at fixation while ignoring the (two or four) other colored shapes presented to the left and right of the center. Participants were asked to be as fast as possible while making few errors.

### Stimuli

Across participants, two different color pairs were used to create the targets: red versus green and yellow versus blue. Likewise, there were two different shape pairs: square versus diamond, and pound sign versus tilted pound sign. One quarter of the participants in each experiment used each of the four possible combinations of color pair and shape pair.

In the standard version of the flankers task, the same colors and shapes were used to create the flanking nontargets, whereas in the correlated flankers task, the unused color and shape pairs were employed. To force the correlations to be based on conjunctions, the four flankers were correlated with the two responses in the same manner as the assignment of targets to responses. For example, *yellow pound sign* and *blue tilted pound sign* might be correlated with a left-hand response and *yellow tilted pound sign* and *blue pound sign* correlated with the right.

### Procedure

Participants began their experimental session with written instructions, followed by four practice blocks during which the targets-to-responses mapping was displayed for 5 sec after an error. The remaining twelve blocks were retained for analysis and only used a brief message to indicate that an error had been made. There was an enforced 7-sec break between blocks, during which a summary of performance on the previous block was provided.

Each trial began with the presentation of a white circle (subtending 9.10º of visual angle) for 350 msec. After a 150-msec blank, the final display was presented until a response was made. The final display in most of the experiments contained three characters, each 0.98º square, with the target appearing at the center of the screen and the middle of each flanker being 1.30º to one side of fixation. In the last experiment, the final displays contained five items, each the same size as above, with the extra two flankers being 2.60º to each side of fixation (i.e., 1.30º further out from the inner flankers). The intertrial interval was 1,500 msec.

There were approximately 36 trials in each block: the 32 planned trials (see Design, below); 3 randomly selected warm-up trials; a recovery trial after each error; and, at a later point in the block, the rerun of the error trial.

### Design

In the conditions using the standard flankers task, each of the four targets appeared equally often with each of the four flankers (see Table 1). Therefore, half of these trials were congruent (i.e., the flankers were associated with the same response as was the target), and half were incongruent. Note how the flankers provided no information about either the identity of the target or the correct response for the trial (see Mordkoff, 1996). In the correlated flankers task (see Table 2), each of the four targets appeared equally often, as did each of the four flankers; but the frequencies of the sixteen combinations were highly unbalanced, with some combinations never occurring. Following the method used by Miller (1987), there were two types of trial: *inducing trials* that establish a correlation between certain flankers and responses, and *test trials* that are used to measure the effect of these correlations without any confounding effect of display frequency. A "positive" test trial is one on which the correlation between the flankers and responses would aid performance (i.e., the flankers were associated with the correct response); a "negative" trial is one on which the correlation would act against the correct response. Only the data from the test trials were analyzed.

## EXPERIMENTS 1 AND 2

Experiment 1 involves the standard flankers task (Eriksen & Eriksen, 1974), under which the unattended items have relationships with the responses only when the instructed S–R mapping is taken into account. Both of the models being considered, therefore, predict no effect of conjunction flankers under these conditions (albeit for different reasons), so this experiment may be thought of as a check of assumptions. Fortunately, no flanker effect was observed in Experiment 1, which replicates previous failures using conjunction flankers under similar conditions (e.g., Cohen & Shoup, 2000).

Experiment 2 employs the correlated flankers task (Miller, 1987), under which the unattended items are associated with responses by correlating their presence with

**Table 1**
**Experimental Design (Trials per Block) for the Standard Flankers Task**

| Target | Correct Response | Number of Trials per Block With Each Flanker | | | |
|---|---|---|---|---|---|
| | | C1S1 | C2S2 | C1S2 | C2S1 |
| C1S1 | Left | 2 C | 2 C | 2 I | 2 I |
| C2S2 | Left | 2 C | 2 C | 2 I | 2 I |
| C1S2 | Right | 2 I | 2 I | 2 C | 2 C |
| C2S1 | Right | 2 I | 2 I | 2 C | 2 C |

Note—Cells marked C, congruent trials; cells marked I, incongruent trials. For example, C1S2 indicates a stimulus that comprises Color 1 and Shape 2, which, in this case, is assigned to the right-button response via the instructions.

**Table 2**
**Experimental Design (Trials per Block) for the Correlated Flankers Task**

| Target | Correct Response | Number of Trials per Block With Each Flanker C3S3 | C4S4 | C3S4 | C4S3 | Trial Type |
|---|---|---|---|---|---|---|
| C1S1 | Left | 4 | 4 | 0 | 0 | Inducing |
| C2S2 | Left | 2 + | 2 + | 2 − | 2 − | Test |
| C1S2 | Right | 2 − | 2 − | 2 + | 2 + | Test |
| C2S1 | Right | 0 | 0 | 4 | 4 | Inducing |

Note—Cells marked with + are positive-correlation test trials; cells marked with − are negative-correlation test trials. C3S4, for example, indicates a stimulus that comprises Color 3 and Shape 4, which here is correlated with the right-button response, since six of the eight trials (per block) that include this conjunction require a right-hand response.

the need to make a certain response. Because the correlated flanker effect does not rely on the S–R mapping, the model that allows separable features to be integrated without attention here predicts a significant finding. In contrast, any model claiming that attention is required for feature integration must again predict no effect, because the items from which the correlations derive are unattended conjunctions.

### Method

Different groups of 24 undergraduates participated in each experiment for course credit. Each participant was tested in a single session lasting about 45 min. Experiment 1 was a standard flankers task. Experiment 2 was a correlated flankers task.

### Results and Discussion

Experiment 1 produced nearly identical data in the congruent and incongruent conditions (mean and standard error of the difference, 0±6 msec), with mean response times (RTs) of 653 msec in both conditions [$t(23) = 0.08$] and error rates of 5.4% and 5.6% in the congruent and incongruent conditions [$t(23) = 0.46$]. In contrast, Experiment 2 produced a reliable correlated flanker effect (10±4 msec), with mean RTs of 632 msec and 642 msec in the positive and negative conditions, respectively [$t(23) = 2.51$, $p < .05$], and error rates of 4.8% and 5.6% [$t(23) = 1.20$].

Experiment 1 has replicated the pattern of results that could be cited as evidence that the separable features of unattended items are not integrated. However, Experiment 2 has shown that these same unattended conjunctions can have an effect if they are associated with responses by conditioning, as opposed to an instructed S–R mapping. The most parsimonious explanation of this pattern is that visual features are integrated in the absence of attention but cannot undergo an arbitrary S–R translation without being attended.

## EXPERIMENT 3

Experiments 1 and 2 have provided prima facie evidence that the separable features of a visual object can be integrated in the absence of attention. However, a crucial difference between the standard and correlated versions of the flankers task provides an alternative to this conclusion. Note that, in the correlated version of the task, the specific color–shape conjunctions that are explicitly assigned to the two responses never appear anywhere other than the central, task-relevant location. Therefore, it could be argued that the correlated flankers task does not require selective attention; instead, attention could be spread across the entire display. If this were true, the finding of a significant effect with correlated conjunction flankers would not be strong evidence in favor of feature integration in the absence of attention.

To test this alternative, Experiment 3 mixed the designs of Experiments 1 and 2, with the trials occurring in an unpredictable order. This should prevent participants from spreading attention on correlated flankers trials, since they would have to be prepared for a standard flankers trial (see Eriksen & Eriksen, 1974, for direct evidence of this). If attention were being spread in Experiment 2 because of the lack of any standard flankers (and attention is required to integrate features), Experiment 3 should not produce a correlated flanker effect. However, if attention were not being spread in Experiment 2, the two "halves" of this new experiment should replicate Experiments 1 and 2.

### Method

Thirty-six additional undergraduates were recruited. The experimental design was a simple combination of the two designs used for Experiments 1 and 2 (with all cell frequencies divided by two, such that each block was still about 36 trials long). The same targets-to-responses mapping was employed for both the standard and correlated flankers tasks, rendering the task-relevant mapping as complex in Experiment 3 as in Experiments 1 and 2.

### Results and Discussion

As was true for Experiment 1, the standard flankers did not produce a reliable effect (−3±6 msec), with mean RTs of 651 msec and 648 msec for the congruent and incongruent conditions, respectively [$t(35) = 0.45$], and error rates of 4.3% and 4.5% [$t(35) = 0.76$]. In contrast, but matching Experiment 2, there was a significant correlated flanker effect (15±5 msec), with mean RTs of 635 msec and 650 msec in the positive and negative conditions, respectively [$t(35) = 3.08$, $p < .05$], with error rates of 4.3% and 3.4% [$t(35) = 1.78$]. Furthermore, this difference between the standard and correlated effects was significant in RT [$F(1,35) = 5.34$, $p < .05$] but not in error rate [$F(1,35) = 1.42$]. In short, Experiment 3 would appear to rule out the alternative explanation, according to which separable features require attention to be integrated: There is no evidence that the significant correlated flanker effect that was observed in Experiment 2 was due to participants spreading their attention, since identical results have now been found under conditions where attention would seem to be forced to be consistently focused.[1]

## EXPERIMENT 4

Whereas Experiment 3 did mix the standard and correlated trials together within blocks, one could still argue that certain aspects of the displays might have allowed the participants to quickly shift to dividing their attention across all items on those trials with correlated flankers. To address this alternative, Experiment 4 included both standard and correlated flankers within every display. Even more, the standard flankers were always placed directly adjacent to the target whereas the correlated flankers were placed farther away, such that any spreading of attention to encompass the correlated flankers would have to include the standard flankers.

To accomplish this, every display in Experiment 4 included either congruent or incongruent flankers immediately adjacent to the target, and every display also included correlated flankers to the outside of the standard flankers. The standard and correlated designs were combined orthogonally: Whether the standard flankers were congruent or incongruent was unrelated to the type of correlated flankers also included within the same display.[2]

### Method

Twenty-four additional undergraduates were recruited from the same pool. The experimental design was based mostly on that shown in Table 2 (i.e., a correlated flankers design), which determined the items to be included in the distal locations. The one change was that half of all trials also included congruent standard flankers in the adjacent positions; the other half included incongruent standard flankers. As before, the mapping of specific color and shape pairs was counterbalanced across participants.

### Results and Discussion

A preliminary analysis tested for any interactions between standard flanker condition and correlated flanker condition (since both effects could occur on every trial, in contrast with Experiment 3). There was no evidence for such in either mean RT or error rate [both $F$s(1,23) $<$ 1], so the two types of effect were analyzed separately (to parallel the analysis used previously).

The standard flankers did not produce a reliable effect ($-8 \pm 6$ msec), with mean RTs of 759 msec and 751 msec for the congruent and incongruent conditions, respectively [$t(23) = 1.47$], and error rates of 3.5% and 4.3% [$t(23) = 1.33$]. In contrast, the correlated flankers had a significant effect ($14 \pm 7$ msec), with mean RTs of 748 msec and 762 msec in the positive and negative conditions, respectively [$t(23) = 2.17$, $p < .05$], and error rates of 3.9% and 3.8% [$t(23) = 0.30$]. As was true for Experiment 3, the difference between the two effects was reliable using RT [$F(1,23) = 4.56$, $p < .05$] but not error rate [$F(1,23) < 1$]. Thus, Experiment 4 makes it clear that correlated conjunctions can have effects on performance even when placed in locations not being attended. The simultaneous observation of no standard flanker effect, even though these items were placed closer to the target than were the correlated flankers, greatly strengthens this conclusion. If a small amount of attention were being paid to the flankers, or if attention were switched to the flankers on a small proportion of the trials, one would expect a standard flanker effect, especially given the acuity advantage of items that are closer to fixation.

## GENERAL DISCUSSION

If discussion is confined to tasks involving the conjunction of surface features (i.e., color and shape, not motion or depth) and requiring an arbitrary response (e.g., target detection or forced-choice discrimination, not aftereffects), the previous literature is consistent with the idea that attention is required to integrate the separable features of a visual object. The present study, however, has shown that even under this limited range of conditions, visual features can be integrated in the absence of attention, as long as instructed S–R relationships are not required to produce the evidence. Thus, the surface features of color and shape now join with, for example, motion and stereoscopic disparity, in that all appear to be integrated, even when unattended. Similarly, the popular laboratory RT tasks now join with those using, for example, self-report measures, in that they can all provide evidence of feature integration in the absence of attention.

One way to conceptualize the entire pattern of results from RT tasks involving colored shapes is to posit that attention is not needed to integrate these separable features, but that it is required to make the connection between a given conjunction and the response to which it has been assigned. Expressed differently, the new idea is that attention is only necessary when both of two conditions are met: First, the items in question must involve a conjunction of features; second, the items must require processing by central systems (e.g., S–R translation) in order to have an effect. Standard single-feature flankers (such as those used by Eriksen & Eriksen, 1974) have effects, because these stimuli do not meet the first condition, making attention unnecessary. Conversely, correlated flankers never need to be processed by central systems, since their effects are due to conditioned links between stimuli and responses; therefore, both single-feature and conjunction flankers can have correlational effects in the absence of attention. However, standard conjunction flankers meet both of the criteria, so they cannot have effects when the items are unattended.

There are at least two alternatives to the idea that attention is not necessary for feature integration that, although arguably less plausible, are consistent with all of the evidence to date. The first alternative would posit that visual features are initially registered as conjunctions, then parsed along their separable dimensions, and finally "reintegrated" at some later point. The conjunction-based aftereffects (Houck & Hoffman, 1986) and correlational effects (present results) could then be argued to arise at the first of these levels, before the visual features have been separated; this would allow theorists to continue to claim that feature integration (which is here being relabeled as "reintegration") requires attention. In fact, given recent physiological evidence of visual-feature conjunctions at very "early" levels of processing, such as V1 (e.g., Li, 2002), this alternative could be said to enjoy some support, even if the idea that feature integration doesn't require attention is also consistent with these other data.

The second alternative would suggest that the evidence in favor of feature integration in the absence of attention is rooted in a completely different system from the one in which most researchers are interested. For example, it could be argued that all correlational effects, including those derived from color–shape conjunctions, arise within the colliculo-tectal pathway and, therefore, have little to say about the processing that occurs within the geniculo-striate pathway. Expressed differently, one could say that correlation effects are the signature of the reptilian brain, whereas the ability to make arbitrary, instruction-based responses (without any training) is exclusively that of the mammalian brain. It should be noted, however, that regardless of any remaining questions concerning the level of processing or the system of origin, it would appear to be time to abandon the idea that the integration of color and shape always requires that attention be paid to the stimulus.

## AUTHOR NOTE

The authors thank Steve Luck for suggesting Experiment 4, Todd Horowitz for suggesting the follow-up analyses to Experiment 3, and the other reviewers for their feedback on the text. Correspondence concerning this article should be addressed to J. T. Mordkoff, Department of Psychology, Seashore 11 E, University of Iowa, Iowa City, IA 52240 (e-mail: jonathan-mordkoff@uiowa.edu).

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## NOTES

1. It is worth noting, as well, that a post hoc analysis can be used to rule out a more sophisticated version of this alternative. According to this model, participants spread their attention on a subset of trials, such as those which do not follow an incongruent (standard flankers) display. We tested this alternative by recalculating and reanalyzing both the standard and correlated flanker effects using subsets of the data defined in terms of the type of trial that occurred immediately before. In every case, the standard flanker effect was within 5 msec of zero (and unreliable), whereas the correlated flanker effect was at least 9 msec (although often unreliable due to small sample sizes). In summary, we found no evidence that participants were spreading their attention on even a subset of the trials; this strengthens the conclusion that the correlated flanker effects that were found are truly occurring in the absence of attention.

2. One other change was made to the method to rule out another alternative explanation of the correlation effects of conjunction flankers. In all three of the previous experiments, the two flankers that were included in any given display were always identical. Because of this, it could be argued that the integration of features was not (strictly) necessary in order to produce the correlation effect: Instead, the effects could be based on the mere presence of two features at the same time (cf. the "both" task of Moore & Osman, 1993). To prevent this possibility, the two flankers of a given type were always associated with the same response, but were always different (e.g., one flanker being a *red square* and the other being a *green diamond*). In this way, all four flanker features—the two colors and the two shapes—were always included. What varied across trials was how they were combined, forcing the colors and shapes to be treated as conjunctions in order to have an effect.

(Manuscript received August 28, 2006;
revision accepted for publication September 12, 2007.)