THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 2000, *53A* (1), 191–209

Interference From Multi-dimensional Objects During Feature and Conjunction Discriminations

Lisa R. Fournier, Christopher Bowd, and Rhonda J. Herbert
Washington State University, Pullman, Washington, U.S.A.

Feature discrimination performance within an attended object and interference from irrelevant, multi-dimensional objects (distractors) were examined in a two-choice, response compatibility paradigm. Results showed that the amount of interference by multi-dimensional distractors was dependent on three factors: (1) the discriminability of the incompatible, task-relevant distractor features; (2) the number of incompatible, task-relevant distractor features; and (3) whether the task-relevant, incompatible features matched the task goals. The most interesting finding was that additive priming effects were found for multiple, task-relevant features that matched the task goals, whether these features were present in the attended object or in the ignored object. Models that assume that each task-relevant feature primes its corresponding decision/response asynchronously and that this priming is combined to meet a decision/response criterion (at least when attended) can account for distractor interference during conjunction discriminations. Implications of these findings for feature integration models, template models, and a response selection model are discussed.

It is generally assumed that task complexity increases when two or more features must be determined to match a particular stimulus category relative to one feature (Wickens, 1984). Also, common sense suggests that comparing more information should require more time or may be time limited by the most difficult comparison. However, Fournier, Eriksen, and Bowd (1998) provide evidence that is inconsistent with such predictions. They had observers judge the presence or absence of one or two target features within an object. The object was a letter that varied in colour (red or green) and shape (H or K), and colour was easier to discriminate than shape. They found that judging the presence of the colour-shape conjunction was faster and more accurate than judging the presence of the less discriminable target feature of shape alone. Faster present responses for conjunctions relative to the less discriminable feature are referred to as "conjunction benefits". Also, absent responses, required when one or both target features were not present within an object, showed similar response patterns for single and conjunction feature judgements,

Request for reprints should be sent to Lisa R. Fournier, Department of Psychology, Washington State University, Pullman, WA 99164–4820, U.S.A. Email: fournier@wsunix.wsu.edu

We thank Brian Dyre, Bernhard Hommel, Kyle Cave, and Bob Patterson for their comments and suggestions concerning this manuscript.

but only when all task-relevant features were absent. Absent responses for conjunction judgements were slower and less accurate when one of the target features was absent and the other was present, especially when the target feature that was present was more discriminable. Slower absent responses for conjunctions when a target feature is present are referred to as "conjunction costs". These findings indicate that evaluating more information does not always take longer if all relevant information is compatible with the correct response.

Fournier et al. (1998) concluded that models assuming asynchronous priming of decisions/responses could accurately predict conjunction benefits and costs. One such model is the asynchronous priming (AP) model proposed by Fournier et al., which is similar to the asynchronous discrete coding model discussed by Miller (1982a). The AP model assumes that all object features are processed in a parallel, independent fashion and that each feature primes its task-relevant response (e.g. "present" or "absent"). On average, easily discriminated features (e.g. colour red/green) are assumed to prime their responses before less discriminable features (e.g. shape H/K; see also Grice, Boroughs, & Canham, 1984; Grice, Canham, & Schafer, 1982). In addition, it is assumed that priming from different features are combined to meet a response criterion (e.g. Miller, 1982a, 1982b; see also Ratcliff, 1978). This may lead to conjunction benefits when all features are mapped to the *correct* response (e.g. present or absent). That is, priming by the less discriminable features can benefit from early priming by more discriminable features. Conjunction costs result when one feature primes the *incorrect* (e.g. present), and another feature primes the correct (e.g. absent) response. For this case, correct responses will be slowed due to the time required to override incorrect (e.g. present) priming (Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979). Costs will be greater if the more discriminable feature is mapped to the incorrect (e.g. present) response because more incorrect priming will accumulate and will need to be overridden. Thus, the speed of response depends on the discriminability of the features mapped to the correct or incorrect response.

Most evidence for the AP model was based on discriminating features within a single, task-relevant, attended object. Because the AP model applies to objects in general, and not just to attended target objects, it is of interest to determine whether conjunction benefits and costs apply to all objects in a stimulus array, including objects that might interfere with discrimination of a target object. Therefore, we were interested in whether the AP model could generalize to processing of task-irrelevant (distractor) objects. Fournier et al. (1998, Experiment 3) provide some data relevant to this issue. They evaluated distractor interference in order to demonstrate that multiple feature benefits were not due to biased weighting of the more discriminable feature during conjunction target judgements. Thus, some of the data analyses necessary to test the AP model were not carried out. However, the methods used and some of the results found by Fournier et al. are directly relevant to the issue of whether the AP model can be generalized to the processing of irrelevant information.

Fournier et al. (1998) had observers judge the presence or absence of one or more target features based on a specific colour, shape, or colour–shape conjunction within a cued, multi-dimensional object (probe). At the same time, they were to ignore multi-dimensional distractors that flanked this probe object (flankers). Data relevant to the AP model concerns conjunction target trials in which flankers contained one or two features that were incompatible with the probe. Examples of the stimulus displays are presented in Figure 1 (note, however that the shapes used by Fournier et al. were different). The AP model predicts that the more discriminable feature (i.e. colour) should prime its associated incompatible response earlier than the less discriminable feature (i.e. shape). Thus, greater interference for colour–shape conjunction judgements should be observed when the more discriminable of the two flanker features (i.e. colour) is incompatible with the probe. This result was obtained by Fournier et al., but only when the flanker feature that was *incompatible* with the probe feature *matched* one of the target features. For example, when the target features were "green O" and the probe was a red X flanked by green Xs (i.e. the flanker colour green was incompatible with the probe colour red, Figure 1d, but matched the target feature green), discrimination RTs were longer than when this probe was flanked by red Os (i.e. the flanker shape O was incompatible with the probe shape X, Figure 1c, but matched the target feature O). If the flanker feature that was *incompatible* with the probe feature did *not* match a target

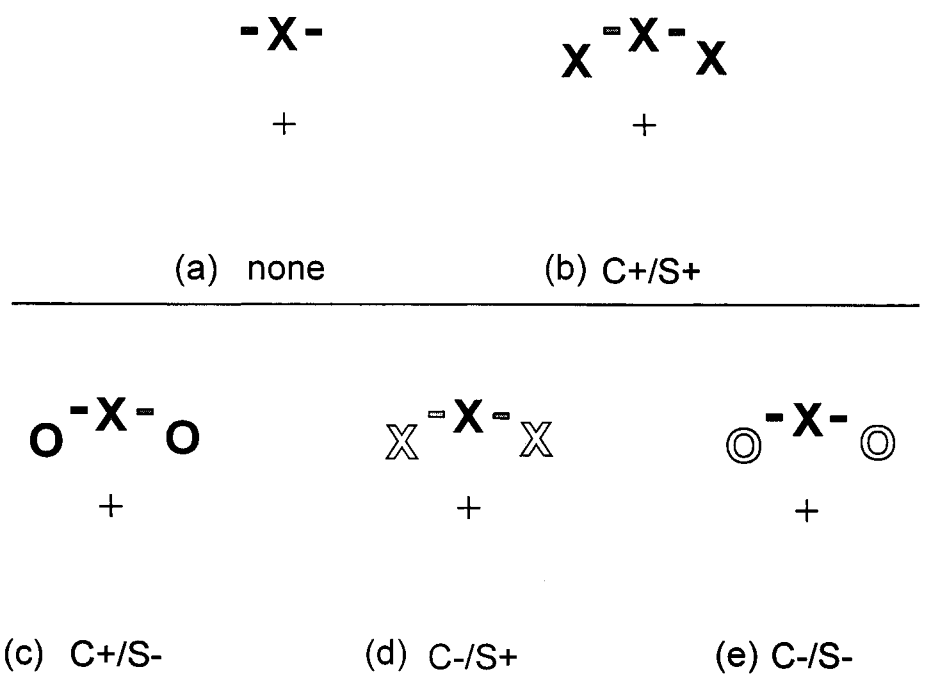

FIG. 1. Example stimulus arrays where black letters represent the colour red, and white letters represent the colour green. The probe is the centre letter, and the flankers are the letters to the left and right of the probe. Each flanker feature condition is as follows: (a) none = no flankers, (b) C+/S+ = flanker identical to the probe, (c) C+/S− = flanker shape different from the probe, (d) C−/S+ = flanker colour different from the probe, (e) C−/S− = flanker colour and shape different from the probe. Note that if the target features to be discriminated are "green O", then the flanker features that are incompatible with the probe (C+/S−, C−/S+, and C−/S−) match the target features; if the target features to be discriminated are "red X", then the flanker features that are incompatible with the probe (C+/S−, C−/S+, and C−/S−) do not match the target features.

feature, discriminability of the incompatible flanker feature did not influence the amount of interference. For example, when the target features were "red X", and the probe was a red X flanked by green Xs (i.e. flanker colour green was *incompatible* with the probe colour red, Figure 1d, but did *not* match the target feature red), discrimination RTs were no different from those when this probe was flanked by red Os (i.e. flanker shape O was *incompatible* with the probe shape X, Figure 1c, but did *not* match the target feature X). Note also that none of the probe features matched the target features in the former case, and both of the probe features matched the target features in the latter case.

The AP model, in contrast, predicts discriminability-based interference independent of whether an incompatible flanker feature matches or does not match a target feature. Perhaps incompatible flankers that did not match the target features interfered in an asynchronous fashion, but mean RTs were not sensitive to these differences when the probe contained both target features. In this case, conjunction benefits should occur for the probe, which may mask small differences in discriminability-based flanker interference. Also, Fournier et al. (1998) precued the probe location by 150 msec, which is known to reduce flanker interference (e.g. Fournier, 1994). A more sensitive measure that evaluates RT distributions for these flanker conditions may reveal evidence consistent with asynchronous priming.

More importantly, the AP model predicts that flanker features that are incompatible with the probe on both relevant dimensions (Figure 1e) should cause more interference for conjunction target judgements than those in which only one of these dimensions is incompatible and the other is compatible (Figures 1c and 1d). This is because flanker features that prime a consistent response (e.g. present or absent) will accumulate more priming consistent with a single response earlier than flanker features that prime different responses (e.g. present and absent) and lead to conjunction costs. Results obtained by Fournier et al. (1998) failed to support this prediction when flanker features that were incompatible with the probe did not match any of the target features. For example, when the target features were "red X" and the probe was a red X (which required a present response), the flankers that were green Os (Figure 1e) did not interfere more with probe discrimination than did the flankers that were green Xs or red Os (Figures 1d and 1c, respectively). Again, it is possible that probe conjunction benefits and precueing the location of the probe masked small increases in interference when both flanker features were incompatible with the probe. Fournier et al. did not evaluate interference by flankers when both flanker features were incompatible with the probe and matched both target features—that is, the target features were "green O", the probe was a red X (which required an absent response), and the flankers were green Os (Figure 1e). This latter condition could not be evaluated because absent response conjunction trials included trials in which both probe features were mapped to the absent response and trials in which one probe feature was mapped to the absent response and the other was mapped to the present response. Thus, it is unknown whether absent response delays for conjunction judgements were based on the response-incompatible distractor features or on the response-incompatible features contained within the probe (see discussion by Fournier et al.).

It is interesting that Fournier et al. (1998) failed to find flanker interference consistent with the AP model when the incompatible flankers did *not* match the target features to be discriminated. They found evidence consistent with the AP model only in the one case where a flanker feature was incompatible with the probe and matched one of the target features to be discriminated. Flankers that match the target features to be discriminated also match the observer's task goals. Perhaps flankers that match these goals are more likely to capture attention than flankers that do not. Folk, Remington, and Johnston (1992) provide evidence that task-relevant distractors may have a higher probability of initially capturing attention. If this is true, flanker interference should be overall greater for conjunction judgements when the flanker matches one or both target features (i.e. task goals) and the probe does not. For example, if the target features are "red X", probe discrimination should be longer when the probe is "green O" *and* the flankers are "red X" than when the probe is "red X" *and* the flankers are "green O". This is because selection of the flankers should allow priming by flanker feature(s) to occur before the probe feature(s). Increasing the probability of flanker selection may also increase the sensitivity of finding mean RT differences in flanker interference based on the discriminability of flanker features and on the number of flanker features mapped to the incompatible response. This possibility can be evaluated by examining RT distributions for conjunction target judgements when incompatible flankers match the target features (task goals) and do not match the target features (task goals).

If, however, the predicted interference patterns for incompatible flankers occur only when these features match the target features (task goals), this would suggest that decisions/responses are not automatically coded or primed by each individual task-relevant dimension. It may be that response coding/priming occurs only after the serial process of object selection. This assumption is consistent with many visual attention models (e.g. Cave & Wolfe, 1990; Duncan & Humphreys, 1980, 1992; Treisman & Sato, 1990; Wolfe, Cave, & Franzel, 1989).

The purpose of the present study was to evaluate the interference by task-irrelevant objects and to determine whether the AP model can generalize to the processing of irrelevant objects. This study extends Fournier et al.'s (1998) Experiment 3 by examining untested interference effects predicted by the AP model, examining interference effects when distractors match or do not match the task goals, and evaluating response distributions of flanker interference. Observers judged the presence or absence of one or two target features. The probe and flankers varied in colour (red or green) and shape (X or O), and colour was easier to discriminate than shape (determined by response RT and accuracy). Also, to maximize interference by flankers, the probe location was cued by dashes simultaneously with probe–flanker onset (instead of using a precue). An example of the flanker conditions is shown in Figure 1.

The AP model predicts flanker interference when a flanker feature is incompatible with the probe on one or more of the task-relevant dimensions. Interference should be greater (higher RTs and/or error rates) for colour–shape conjunctions when the flanker colour and shape are incompatible (C−/S−) than for those when only the flanker shape (C+/S−) or colour (C−/S+) is incompatible with the probe. Also, if colour (red/green) is more salient and is processed faster than shape (X, O), interference should be greater for colour–shape conjunctions when the flanker colour (C−/S+) as opposed to shape

(C+/S−) is incompatible with the probe. These interference patterns are predicted to occur whether or not the incompatible flanker features match the target features, although these differences in interference are expected to be greater for features that match the target features. Moreover, increases in RT interference should be related to increases in priming lead time for the incorrect response (Grice et al., 1984) as evidenced by cumulative probability density function (CDFs).

Method

Subjects

A total of 16 right-handed undergraduates, 6 males and 10 females, from Washington State University participated for optional research credit in a psychology course. All had normal colour vision as assessed by the Pseudo-Isochromatic Plates for Testing Color Perception (1940) and 20/20 acuity as assessed by a Snellen Chart.

Apparatus and Stimuli

Stimuli were presented on a computer screen, and observers viewed these stimuli through a face mask to keep stimulus distance constant. Stimuli consisted of one or three letters that varied in shape (X, O) and colour (red, green). The degree of visual angle for each letter measured 0.23° in width and 0.46° in height. Luminance was 2.98 cd/m^2 for green-coloured letters and 1.04 cd/m^2 for red-coloured letters. Letter stimuli appeared among eight possible locations of an imaginary circular display. All letter stimuli appeared at a distance of 2.10° visual angle from the fixation cross (0.20° visual angle). When multiple letters were presented, these letters appeared in adjacent clock locations with a spatial separation of 1.57° visual angle.

Procedure

Observers were instructed to attend to a single target letter (probe) that could appear in any one of eight locations and to ignore any noise letters that flanked the probe. Probe and flankers consisted of red or green Xs and Os. The probe location was indicated by two white dashes (cue) that appeared to the left and right of the probe (0.6° centre-to-centre cue–target distance). Probe, cue, and flankers appeared simultaneously for 150 msec.

Observers judged whether a specific target feature or conjunction of target features were present or absent in the probe. A present response was required when all of the target features were present. An absent response was required when any one of the target features was absent. One half of the observers moved the hand-lever to the right for a present response and to the left for an absent response. The other half of the observers had the opposite hand-lever response assignment. Observers were instructed to respond as quickly and as accurately as possible. Present/absent response direction was held constant for each participant.

The target features that observers judged as present or absent (target feature judgements) were varied across blocks of trials. Thus, observers looked for a specific colour, a specific shape, and a specific colour and shape across blocks. In addition, each subject was assigned to one of four specific target feature combinations (i.e. red X, red O, green X, green O). Thus, any given participant was asked only to make present judgements for one specific target feature combination (e.g. red, X, and red X).

The similarity between probe features and flanker features varied within blocks. There were five levels of flanker feature: (1) no flanker (none), (2) flanker identical to probe (C+/S+), (3) flanker shape different from probe (C+/S−), (4) flanker colour different from probe (C−/S+), and (5) flanker colour and shape different from target (C−/S −). See Figure 1.

A message was presented at the beginning of each block that indicated which one or two target features to discriminate within the probe. This message was displayed until the hand button was pressed to clear the screen. After reading the message, the sequence of trials began.

The sequence of events for each trial was as follows. A small circle 0.20° of visual angle appeared in the centre of the monitor. Approximately 1 sec later, this circle was replaced by a fixation cross. The subject was to fixate the cross before initiating a trial. Each trial was initiated by pressing the hand button when the fixation cross was in clear focus. Immediately after pressing the hand button, the stimulus display followed. Subjects had 2 sec to respond present or absent. Response RT and accuracy feedback were presented after each trial.

Observers completed a total of four sessions consisting of 12 blocks (4 blocks of each target feature judgement). The first session was practice and was not included in the data analyses. Target feature judgements (colour; shape; colour and shape) were blocked, and block order was counterbalanced across sessions within and betweeen observers. The colour alone and shape alone target judgements contained 40 trials per block, and the colour–shape target judgement contained 60 trials per block. Probe location and flanker condition occurred equally often in a random order within blocks. In addition, probes requiring a present response and probes requiring an absent response were presented with equal occurrence within each block.

Results and Discussion

Consistent with Fournier et al. (1998), Figure 2 shows that conjunction benefits occurred for present responses. Also, consistent with expectations, Figure 3 (Panels A, B, and C) shows that incompatible flanker features that were task relevant and matched the task goals (see absent responses) interfered more with target feature discrimination than did incompatible flanker features that did not match the task goals (see present responses). That is, absent response latency was greater than present response latency when a flanker feature was incompatible with the probe on a task-relevant dimension. Furthermore, the pattern of flanker interference for conjunction judgements (Figure 3C) differed when the incompatible flanker features matched the task goals (absent responses) compared to when they did not (present responses). Evaluation of this asymmetrical pattern of interference and its implications for the AP model and other models will be discussed in detail later.

A four-way, repeated measures ANOVA, 3 (Session) $\times$ 2 (Response) $\times$ 3 (Target Feature) $\times$ 5 (Flanker Feature), was conducted on RT and accuracy data. Significant effects for RTs and accuracy are presented in Table 1. Planned F comparisons were based on 1 and 15 degrees of freedom. The criterion for statistical significance was $p < .05$ for all analyses.

Conjunction Benefits

Figure 2 shows that the present and absent RTs for the colour judgement were faster (and no different in accuracy) than those for the shape judgement (main effect of target feature). This indicates, as expected, that colour was more discriminable than shape. In

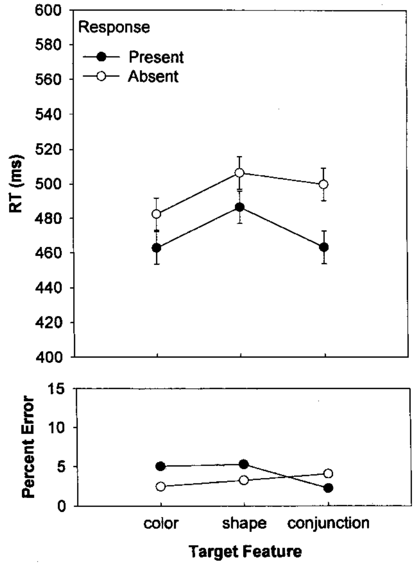

FIG. 2. Correct present and absent RTs and errors for each target feature judgement collapsed over flanker condition.

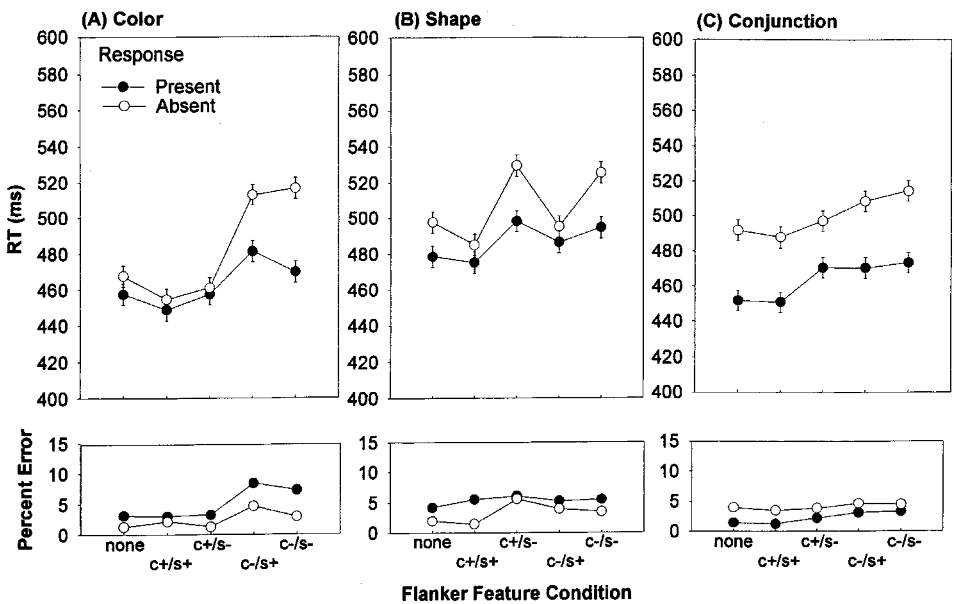

FIG. 3. Correct present and absent response RTs and errors for each of the target feature judgements (Colour: Panel A, Shape: Panel B, Conjunction: Panel C) across Flanker Feature Condition. Levels of flanker feature are: none = no flanker, C+/S+ = flanker identical to probe, C+/S− = flanker shape different from probe, C−/S+ = flanker colour different from probe, C−/S− = both flanker features different from probe. Note that for colour–shape conjunction targets (Panel C), a flanker feature that was different (i.e. incompatible) from the probe in the absent response case actually matched the target feature to be discriminated, whereas a flanker feature that was different from the probe in the present response case did not match a target feature to be discriminated.

TABLE 1
Correct reaction time and accuracy ANOVA tables for significant effects

Factor	*Significance**	*MSE*
Reaction Time		
Response	$F(1, 15) = 20.94$	11,080
Session	$F(2, 30) = 13.22$	10,885
Target Feature (TF)	$F(2, 30) = 22.19$	3148
Flanker Feature (FF)	$F(4, 60) = 35.27$	1417
Response X TF	$F(2, 30) = 7.98$	1417
Response X FF	$F(4, 60) = 6.78$	783
Session X FF	$F(8, 120) = 2.17$	486
TF X FF	$F(8, 120) = 16.16$	755
Response X TF X FF	$F(8, 120) = 6.13$	563
Accuracy		
Target Feature (TF)	$F(2, 30) = 4.10$	.00364
Flanker Feature (FF)	$F(4, 60) = 11.49$	.00269
Response X TF	$F(2, 30) = 17.93$	.00389
TF X FF	$F(8, 120) = 5.18$	.00224

$^*p < .05$.

addition, Figure 2 shows that conjunction benefits were found for present responses (Response $\times$ Target Feature). Specifically, present responses were faster and more accurate for the conjunction judgement than for the less discriminable target judgement of shape. In fact, the present response latencies for the conjunction judgement were similar to those found for the more discriminable target judgement of colour, and responses were more accurate. These findings are consistent with the AP model and with the findings of Fournier et al. (1998). In other words, processing more information does not necessarily require more time.

Flanker Interference and Task Goals

The AP model predicts that flankers will interfere with target feature discrimination within the probe if the flankers are incompatible with the probe on a task-relevant dimension. Consistent with this prediction and past research (e.g. Cohen & Shoup, 1997; Fournier et al., 1998), both present and absent response RTs increased when the Flanker Feature on a relevant dimension was incompatible with that contained in the probe (See Figure 3; Target Feature $\times$ Flanker Feature interaction). In addition, based on the findings of Folk et al. (1992), it was expected that flankers that match the task goals should have a higher probability of capturing attention than flankers that do not. Thus, incompatible flankers that match the task goals should be attended and interfere more often with target feature discrimination compared to incompatible flankers that do not match the task goals. For example, if the colour judgement is "green", target discrimination should be longer when the probe is red and the flankers are green than when the probe is green and the flankers are red. Because absent response trials were trials in which incompatible flanker features matched the task goals (i.e. target features were absent in the probe, but present in the flankers), incompatible absent response trials were expected to be longer than incompatible present response trials.[1] Results were consistent with this expectation (see Figure 3; Response $\times$ Target Feature $\times$ Flanker Feature interaction). The effects of flanker incompatibility and task goals on target feature discrimination for each target feature judgement are described below.

Colour Target. Responses for the colour judgement (Figure 3A) were significantly longer and less accurate when the flanker colour was different (C−/S+ and C−/S−) from the probe, than when flankers were absent (none). When the flanker shape was different (C+/S −) from the probe, RT and errors did not increase relative to the no-flanker (none) condition. Thus, flankers interfered with the colour discrimination of the probe when the flanker had an incompatible feature on the relevant, colour dimension only.[2] In addition, absent responses were longer (approximately 30–45-msec), but more accurate, than present responses when the flanker colour was different (C−/S+ and C−/S−) from the probe. This finding indicates that the longer RT found for absent responses may be due to a speed/accuracy tradeoff. Thus, it is unclear whether the incompatible flanker feature (i.e. colour) that matched the target feature (absent response) led to more interference.

Shape Target. Responses for the shape judgement (Figure 3B) were significantly longer and less accurate when the flanker shape was different from the probe (C+/S− and C−/S−) than when flankers were absent (none). When the flanker colour was different (C−/S+) from the probe, RTs were not different (but response accuracy was higher) from those when flankers were absent (none).[3] These findings again indicate that the flanker interfered with target discrimination of the probe only when the flanker contained an incompatible feature on the relevant target dimension (e.g. shape). In addition, absent response RTs were inflated (approximately 30 msec) relative to present responses when the flanker shape (C+/S− and C−/S−) was different from the probe. Note that there was no significant difference between present and absent response RTs in the C+/S+ and C−/S+ flanker conditions; although absent response RT was longer (approximately 15 msec) in the no-flanker (none) condition. These findings indicate that the flanker interfered more with the target shape discrimination when the flanker shape matched the target judgement (C+/S− and C−/S−, absent response) than when it did not (C+/S− and C−/S−, present response). Unlike the error results for the colour

[1] Note that this was not the case for conjunction judgements in Figure 3C. For absent responses, the probe could contain one feature mapped to the present response and one feature mapped to the absent response. Figure 4 shows conjunction judgements in which both probe features were mapped to either the present response or the absent response.

[2] Note that present responses in the C−/S− condition were faster than those in the C−/S+ condition when the target judgement was colour. This may be due to greater masking by the flankers in the C−/S+ condition (e.g. target X flanked by Xs) than in the C−/S− condition (e.g. target X flanked by Os).

[3] *Present* response RTs for the C−/S+ condition were not significantly different from those for the no-flanker (none) condition, $p = .24$.

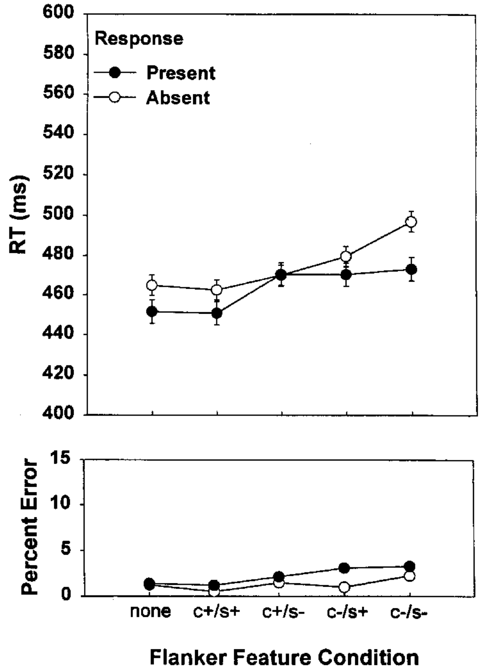

FIG. 4. RTs and errors for the colour and shape conjunction targets when both target features were present in the probe (present responses) and when both target features were absent in the probe (absent responses). Levels of flanker feature: None = no flanker, C+/S+ = flanker identical to probe, C+/S− = flanker shape different from probe, C−/S+ = flanker colour different from probe, C−/S− = both flanker features different from probe. Note that a flanker feature that was different (i.e. incompatible) from the probe in the absent response case actually matched a target feature to be discriminated, whereas a flanker feature that was different from the probe in the present response case did not match a target feature to be discriminated.

target judgement, the error data were consistent with the above RT interpretations and were not indicative of a speed–accuracy tradeoff.

Colour–Shape Conjunction Targets. In Figure 3C, absent responses for the conjunction judgement included trials in which both target features were absent in the probe and trials in which one target feature was present and the other was absent in the probe. On the other hand, present responses for the conjunction judgement consisted only of trials in which both target features (colour and shape) were present in the probe. In order to examine flanker interference on probe feature discrimination, we needed to eliminate any response competition effects within the probe itself (see Fournier et al., 1998). Thus, only those trials in which *both* probe features (colour–shape conjunctions) were mapped to the same response, either present or absent, were examined.

Conjunction trials in which both probe features were either present or absent are presented in Figure 4. A within-subjects, two-way ANOVA (Response × Flanker Feature) was conducted on target conjunction RTs and accuracy. The main effect of response, $F(1, 15) = 5.49$, flanker feature, $F(4, 60) = 22.60$, and the Response × Flanker Feature interaction, $F(1, 60) = 3.43$, were significant for RTs. The main effect of Flanker

Feature was significant for accuracy, $F(4, 60) = 6.43$; accuracy decreased as RT increased (range = 1.5%). As is evident in Figure 4, absent responses were significantly longer (24 msec) than present responses for the C−/S− flanker condition. Similar to the colour-alone and shape-alone judgements, the conjunction judgement was longer when the flanker features were incompatible with the probe and the flankers matched the task goals. For example, if the target features were "red X", then red Xs flanking the probe "green O" led to more interference than green Os flanking the probe "red X".

The general increase in flanker interference when the flanker contained incompatible features that matched the task goals supports the assumption that attention is more likely to be incorrectly captured by these types of distractors. That is, if the target features are *absent* in the probe but present in the flankers, a flanker may (on a proportion of trials) be selected before the probe. Once it is determined that attention is allocated to the incorrect, flanker location, attention may shift to the correct location and select the probe. Early decision/response priming created by the task-relevant features of the initially selected flanker will need to be overridden, which may increase correct decision/response times related to the probe.

Folk et al. (1992) also showed that attention capture is contingent on attentional control settings induced by task demands. They demonstrated that an irrelevant stimulus that contains a task-relevant dimension is more likely to capture attention (see also Egeth & Yantis, 1997). Our data for conjunction judgements further suggest that the probability that a distractor will capture attention is greater if this distractor (e.g. green O) more closely matches the specific task goals of the observer (e.g. determine the presence of a specific colour "green" *and* specific shape "O"). This occurred even though the probe (which did not contain any target features) was always indicated by a peripheral cue. This suggests that top-down factors related to the presence of particular features may allow distractors to draw attention, even when their locations indicate that they are not to be attended.

Influence of Discriminability and Number of Incompatible Flanker Features on Conjunction Judgements

For conjunction judgements, a critical prediction of the AP model is that flankers with incompatible features on multiple, relevant dimensions (C−/S−) should cause more interference than those in which only one of these features is incompatible (C+/S− or C−/S+) with the probe. Also, when only one flanker feature is incompatible with the probe, flanker interference should be greater when the incompatible feature is the more discriminable feature of colour (C−/S+) vs. shape (C+/S−). This pattern of interference is predicted to occur for both present and absent responses.

As shown in Figure 4, this pattern of interference was only observed for absent responses (i.e. incompatible flanker features matched the task goals). Because incompatible flanker features influenced present and absent responses differently (Response × Flanker Feature interaction), these effects were evaluated by planned $F(1, 15)$ comparisons separately for the present and absent response trials.

Present Responses. RT for the conjunction judgement was significantly longer when the flanker was incompatible with the probe on one (C−/S+, C+/S−) or both (C−/S−) relevant dimensions compared to the no-flanker (none) condition. However, there was no difference in the amount of flanker RT interference among the C−/S+, C+/S−, and C−/S− conditions (Fs < 1). This suggests that flanker interference was not influenced by the discriminability differences between colour and shape. Moreover, flanker interference was not greater when both flanker features differed from the probe (C−/S−). Error data are consistent with these RT interpretations.

Absent Responses. Unlike present responses, flanker interference for absent responses was based on the discriminability of features and number of features that were incompatible with the probe. First, when the flanker colour was different from the probe (C−/S+), there was a significant increase in RT (M = 15 msec) relative to the no-flanker (none) condition; whereas there was only a small (M = 5 msec) insignificant increase in RT when shape was different (C+/S−). Second, when both flanker colour and shape were different from the probe (C−/S−), there was a significant increase in absent RT relative to the no-flanker (none; M = 32 msec), the C+/S− (M = 27 msec), and the C−/S+ (M = 17 msec) conditions. This latter finding suggests that feature interference was greatest when both flanker features were incompatible with the probe and matched the target features.

The flanker interference asymmetry found for present and absent response RTs (Figure 4) can be reconciled with the AP model if it is assumed that objects that match the task goals are more likely to be selected first and prime responses earlier than objects that do not. This may occur before it is determined that the selected object is at the incorrect location. If attention facilitates feature processing and/or decision/response priming, objects that are selected early will be able to prime their corresponding decisions/responses (in this case, based on relevant feature dimensions) earlier than other objects. Support for this idea is based on the higher RTs found for incompatible flankers that matched the task goals (absent responses) than those for incompatible flankers that did not (present responses).

Early, incorrect priming may allow differences in interference based on discriminability and on the number of incompatible features to be more salient. For example, if target features are absent in the probe but present in the flankers, a flanker may (on a proportion of trials) be selected before the probe. Once it is determined that attention was initially allocated to the wrong object (based on location information), attention will shift to (or zoom in on) and select the probe. Early, incorrect priming created by the task-relevant features of the originally selected flanker will need to be overridden (time to override priming is based on feature discriminability), which will increase correct decision/response times related to the probe.

In contrast, early, correct priming may mask such differences in flanker interference. If the target features are present in the probe, this may greatly reduce the chance that a flanker is selected before the probe. Again, if attention facilitates feature processing, decision/response priming will occur earlier for the probe than for the flankers (on a large proportion of trials). Incorrect priming by the flanker features should lag behind and generally interfere with longer correct "present" RTs. This, in turn, may mask mean RT differences in interference across the incompatible C−/S−, C−/S+, and C+/S− flanker conditions.

Correct RT CDFs for Present and Absent Responses. CDFs were constructed (bin size = 5 msec) to determine whether the onset of flanker interference is consistent with asynchronous priming and whether priming by flankers that do not match the task goals occurs later than those that match the task goals. Figure 5 shows correct RT CDFs for the flanker conditions of none, C+/S−, C−/S+, and C−/S− for the present responses (Panel A) and absent responses (Panel B). Figure 5B clearly shows that early absent responses were delayed when both flanker features were incompatible (C−/S−) compared to when the flanker colour (C−/S+) or flanker shape (C+/S−) alone was incompatible. In addition, when flanker colour was incompatible (C+/S−/+), early absent responses were delayed compared to when the flanker shape was incompatible (C+/S−). Consistent with these interpretations, an analysis of distribution quartiles, 3 (Quartiles) × 4 (Flanker) showed a main effect of flanker, $F(3, 45) = 8.95$, and quartile, $F(2, 30) = 109.68$, and a Quartile × Flanker interaction, $F(6, 90) = 11.77$. Planned comparisons showed significant RT delays for C−/S− relative to C−/S+, C+/S− and no-flanker (none) conditions at the first quartile. Also, C−/S+ showed significant RT delays relative to the C+/S− and flanker absent (none) conditions at the first quartile. The C+/S− RTs were not delayed relative to the no-flanker (none) condition at any of the quartiles; however, a planned comparison based on skewedness revealed that the C+/S− was significantly skewed to the right relative to the none and C−/S+ conditions. These findings indicate that increased RT interference found for incompatible flankers based on feature discriminability can be attributed to earlier incorrect response priming by the more discriminable feature. Also, the largest increase in flanker interference found for the C−/S− flankers may also be attributed to earlier incorrect priming relative to the C−/S+ and C+/S− flankers. These findings are consistent with the predictions of the AP model.

In contrast, Figure 5A shows that correct present responses were delayed at similar time points across the different incompatible flanker conditions (C−/S−, C−/S+, and C+/S−) relative to the no-flanker (none) condition.[4] An analysis of distribution quartiles showed a significant main effect of flanker, $F(2, 45) = 9.9$, and quartile, $F(3, 405) = 9.91$, but the Quartile × Flanker interaction only approached significance, $F(6, 90) = 1.88$, $p = .09$. Planned comparisons showed that the different incompatible flankers delayed RTs relative to the no-flanker (none) condition and that these delays were greatest at the third quartile and were smallest at the first quartile. This confirms that incorrect priming by these flankers occurred mainly late and influenced slower RTs. However, significant interference by each of the incompatible flankers (C−/S−, C−/S+, and C+/S−) was found as early as the first quartile. Also, there were no significant differences in skewedness among these flankers. These findings are not easily reconciled with the AP model's assumption that task-relevant dimensions automatically prime responses in an asynchro-

[4] Only 5 of the 16 subjects showed clear present response CDF patterns consistent with those found for absent responses.

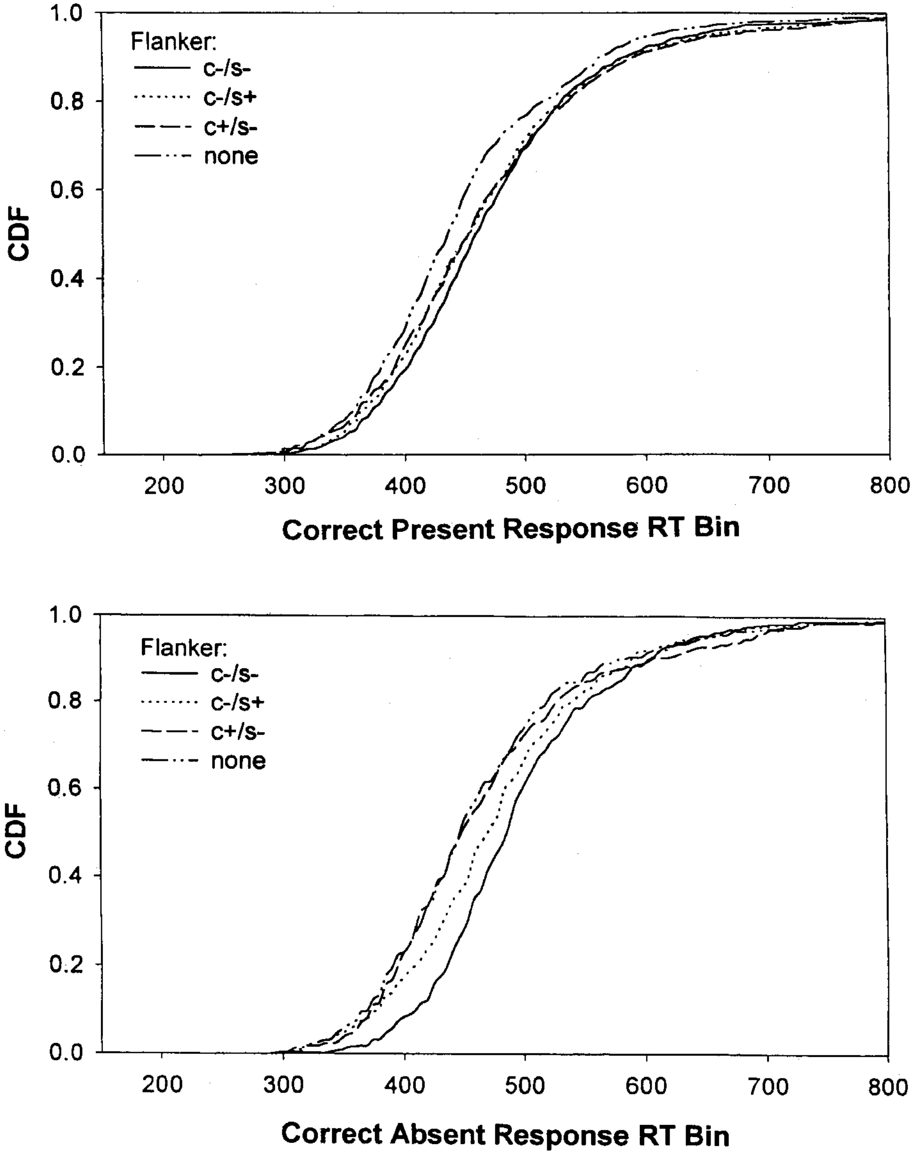

FIG. 5. Cumulative probability density functions (CDFs) based on correct present RTs (Panel A) and correct absent RTs (Panel B) for the flanker feature conditions of: none = no flanker, C+/S− = flanker shape different from probe, C−/S+ = flanker colour different from probe, C−/S− = both flanker features different from probe. Note: Flanker features that were different from the probe in the present response case (Panel A) did not match a target feature to be discriminated, whereas a flanker feature that was different (i.e. incompatible) from the probe in the absent response case (Panel B) actually matched a target feature to be discriminated.

nous fashion, and response priming by these individual dimensions is automatically combined.

Interpretations of Asymmetrical Conjunction Interference Patterns for Present and Absent Responses

One interpretation of our asymmetrical conjunction interference pattern is that decision/responses are *not* automatically coded or primed by each task-relevant dimension. In contrast to the AP model, several attention models such as Guided Search (e.g. Cave & Wolfe, 1990), Feature Integration (e.g. Treisman & Sato, 1990), and Spreading Suppression (template) models (e.g. Duncan & Humphreys, 1989, 1992) assume that decision/response priming *only* occurs after serial selection. These models also assume that one location is selected after a competition among all the stimulus locations. Because the cued location indicates the probe, it will receive some activation (or less inhibition), but each location also receives activation (or less inhibition) according to the target features present. The location with the highest activation (Guided Search), highest selection weight (Spreading Suppression), or least inhibition (Feature Integration) will win the competition and be selected. When both target features are at the cued location, that location will almost always win the competition, regardless of what target features are present in the flanker locations. However, the flanker locations may win the competition on some trials, especially if the target features are not present in the probe. The probability that flankers will win the competition increases with the number of target features present in the flanker locations. Thus, in contrast to the AP model, these models predict additive flanker interference for the C−/S− condition *only* when these features match the target features (i.e. absent response trials). This is consistent with our findings.

However, these models have difficulty explaining the similarities in conjunction interference found for present responses across the incompatible flankers. Interference was similar for incompatible flankers that did not contain any target features (C−/S−) and flankers that contained a target feature and an incompatible, non-target feature (C−/S+ and C+/S−). For example, the conjunction judgement "red X" was similarly delayed when the probe red X was flanked by red Os, green Xs, or green Os. These models, in contrast to the AP model, predict greater interference from distractors that have one feature that matches the task goals (e.g. red Os or green Xs; C+/S− and C−/S+, respectively) than from distractors that have no features that match the task goals (e.g. green Os; C−/S−). The C−/S− flankers that do not match the task goals are least likely to be selected and prime an incorrect response, so interference by these flankers should be minimal. Yet, these models also assume that the probability of flanker selection is extremely low when target features are present in the probe. This low probability of flanker selection could mask small differences among these incompatible flanker conditions.

Furthermore, the Feature Integration and Guided Search models, at present, do not assume that individual features contribute to response activation for conjunction judgements even for attended objects (see discussion by Cohen & Shoup, 1997). Thus, these models have difficulty accounting for conjunction benefits and costs found by Fournier et al. when an object was presented without distractors. Conjunction benefits and costs were determined by the discriminability of the features mapped to the correct and incorrect responses, which suggests that responses are coded and influenced by individual features. To account for benefits and costs within an attended object, these models would have to assume that responses by features individually contribute to a central response selection process, at least for attended objects.

This latter assumption is incorporated in the Response Selection (RS) model recently proposed by Cohen and Shoup (1997). This RS model assumes that features from all objects that belong to a particular dimension (e.g. colour, shape) are analyzed within a corresponding dimension module and responses to single features are determined separately within each dimension module. These modules are linked to a more central response selection process, which combines response activation from the dimension modules and releases the actual motor output. The RS model can account for conjunction benefits (and costs) found for the probe object. However, the RS model, like the AP model, has difficulty explaining the lack of additive interference found for the conjunction judgements when both incompatible flanker features did not match the target features to be discriminated (i.e. C−/S− present responses in Figures 4 and 5A).

The best account for our entire pattern of results appears to be a feature integration model, which assumes that responses by features individually contribute to a central response selection process, at least for attended objects. That is, each feature codes or primes its task-relevant response in an asynchronous fashion (i.e. similar to the AP model), but priming across the features within an object is only integrated if this object is focally attended. This is very similar to the idea that attention integrates features within an object as proposed by Feature Integration Theory (e.g. Treisman & Gelade, 1980) except that for this model, focal attention is assumed to integrate response activation from different features within an object. This assumption could account for our conjunction benefits and costs, increased interference with distractor–target matches, and additive interference found only for incompatible flanker conjunctions that matched the task goals. The similar interference obtained in the C−/S− and C−/S+ conditions when the incompatible features did not match the task goals (i.e. present responses) is accounted for by assuming that these features were not attended on a majority of trials and thus only individual features would contribute to incorrect decision/response priming. However, the lack of feature discrimination differences in incorrect priming between C+/S− and C−/S+ flankers (for present responses) continues to pose a problem, unless these differences are masked by early correct priming by the corresponding probe dimensions.

In general, our findings and findings by Fournier et al. (1998) suggest that individual features can prime their task-relevant responses in an asynchronous fashion and that priming by individual features within the same object can be combined to meet a decision/response criterion. Whether feature response codes are assigned and whether priming occurs prior to selection or is a consequence of selection are not completely clear. In addition, whether selection is necessary to combine priming by individual features within an object to meet a decision/response criterion is also not clear, but our conjunction interference patterns suggest that this is highly probable. Our findings do suggest that processing more does not necessarily take more time, at least for information that is consistent with the specific task goals of the observer. We have also shown that top-down factors related to the presence of particular features may draw attention, even when their locations make it impossible for them to be targets.

CONCLUSION

The amount of interference by multi-dimensional distractors in a two-choice RT task is dependent on three factors: (1) the discriminability of the incompatible, task-relevant distractor features; (2) the number of incompatible, task-relevant distractor features; and (3) whether the task-relevant, incompatible features match the observer's specific task goals. The most interesting finding is that additive priming effects (i.e. combined priming from individual features) are found for multiple, task-relevant dimensions that match the task goals. Models that assume that each task-relevant feature primes its corresponding decision/response asynchronously and that this priming is combined to meet a decision/response criterion, at least when attended, can account for distractor interference during conjunction discriminations. Furthermore, these models can account for conjunction benefits and costs found by Fournier et al. (1998). Taken together, these findings indicate that objects that contain task-relevant conjunctions can lead to earlier decision/response priming than objects that contain a single task-relevant feature.

REFERENCES

Cave, K.R., Wolfe, J.M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology, 22*, 225–271.

Cohen, A., & Shoup, R. (1997). Perceptual dimensional constraints in response selection processes. *Cognitive Psychology, 32*, 128–181.

Duncan, J., & Humphreys, G.W. (1989). Visual search and stimulus similarity. *Psychological Review, 96*, 433–458.

Duncan, J., & Humphreys, G.W. (1992). Beyond the search surface: Visual search and attentional engagement. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 578–588.

Egeth, H.E., & Yantis, S. (1997). Visual attention: Control, representation, and time course. *Annual Review of Psychology, 48*, 269–297.

Eriksen, B.A., & Eriksen, C.W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception of Psychophysics, 16*, 143–149.

Eriksen, C.W., & Schultz, D.W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception & Psychophysics, 25*, 249–263.

Folk, C.L., Remington, R.W., & Johnston, J.C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1030–1044.

Fournier, L.R. (1994). Selective attentional delays and attentional capture among simultaneous visual onset elements. *Perception & Psychophysics, 56*, 536–550.

Fournier, L.R., Eriksen, C.W., & Bowd, C. (1998). Multiple feature discrimination faster than single feature discrimination within the same object? *Perception & Psychophysics, 60*, 1384–1405.

Grice, G.R., Boroughs, J.M., & Canham, L. (1984). Temporal dynamics of associative interference and facilitation produced by visual context. *Perception & Psychophysics, 36*, 499–507.

Grice, G.R., Canham, L., & Schafer, C. (1982). Development of associative and perceptual interference. *Perception & Psychophysics, 32*, 375–387.

Miller, J.O. (1982a). Discrete versus continuous stage models of human information processing: In search of partial output. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 273–296.

Miller, J.O. (1982b). Divided attention: Evidence for coactivation with redundant signals. *Cognitive Psychology, 14*, 247–279.

Proctor, R.W. (1981). A unified theory for matching-task phenomena. *Psychological Review, 88*, 291–326.

Pseudo-Isochromatic Plates for Testing Color Perception (American ed.). (1940). New York, NY: E.B. Meyrowitz Surgical Instruments Co., Inc.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review, 85*, 59–108.

Treisman, A.M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Treisman, A.M., & Sato, S. (1990). Conjunction search revisited. *Journal of Experimental Psychology: Human Perception & Performance, 16*, 459–478.

Wickens, C.D. (1984). *Engineering psychology and human performance* (pp. 1–513). Columbus, OH: Merrill.

Wolfe, J.M., Cave, K.R., & Franzel, S.L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception & Performance, 15*, 419–433.

Original manuscript received 25 February 1998
Accepted revision received 20 December 1998