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Multiple-feature discrimination faster than single-feature discrimination within the same object?

LISA R. FOURNIER
Washington State University, Pullman, Washington

CHARLES W. ERIKSEN
University of Illinois at Urbana-Champaign, Champaign, Illinois

and

CHRISTOPHER BOWD
Washington State University, Pullman, Washington

In the present study, we investigated whether judging the presence of multiple features within an object would be superior to judging the presence of only one feature. Feature discriminability and the number of features to discriminate within an object were varied. Specific features were judged as present or absent. Results showed that judging the presence of two or three features was faster than judging the presence of the less discriminable of these two or three features alone (multiple-feature benefits). These findings suggest that relevant features within an object activate (prime) a decision or response in a parallel, asynchronous fashion based on discriminability (Miller, 1982a). The ability of a response priming model, a response mapping model, and a template model to account for multiple-feature benefits is discussed.

It is generally assumed that task complexity increases when two or more features, relative to one feature, must be determined to match a particular stimulus category (Wickens, 1984). Such multifeature judgments are typical in tasks of pattern recognition. Common sense suggests that comparing more information may require more time or may be time limited by the most difficult comparison. Such predictions are made by simple serial and parallel processing models, respectively, that assume that features within an object are processed in an independent, discrete fashion (e.g., Nickerson, 1972; Sternberg, 1969). However, there is evidence that is inconsistent with such predictions. For example, in *same–different* tasks, it is typically found that *same* judgments are faster than *different* judgments, even though *same* judgments require that all object features be judged as *same*, whereas *different* judgments require that only one feature be judged as *different* (e.g., Bamber, 1969; Hawkins, 1969; Miller & Bauer, 1981; Nickerson, 1972; Proctor, 1981). In the present study, we investigated another empirical phenomenon that also appears inconsistent with simple serial and parallel models.

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In preliminary experiments, we have found that judging the presence of two or more features within an object can be faster than judging the presence of a single feature alone. We first encountered this phenomenon when attempting to vary attention processing demands by varying both feature discrimination and the number of target features to attend to within a single object (see Fournier & C. W. Eriksen, 1991). The object was a letter stimulus that varied across the three attributes of color (red or green), shape (the letter S or the letter C), and size (large or small). Discrimination difficulty varied across these three different features: The color discrimination was relatively easy, the shape discrimination was more difficult (because the letters shared similar features), and the size discrimination was the most difficult (because the large stimulus was only 22% larger than the small stimulus). The number of target features (one, two, or three) within the object also varied. The observers judged the presence or absence of one or more features of an object letter embedded in a circular array of distractor letters. The location of the relevant object letter was cued by a bar marker either simultaneously with or at various intervals before letter display onset.

Consistent with expectations, we found that "present" and "absent" responses among the one-feature judgments were fastest and most accurate for color, intermediate in speed and accuracy for shape, and slowest and least accurate for size. But, surprisingly, we found that judging the presence of combined size and color (two features) and combined shape and size (two features) was faster and more accurate than judging the presence of size alone

(one feature). In addition, judging the presence of combined shape and color (two features) was faster and more accurate than judging the presence of shape alone (one feature). Moreover, judging the presence of all three features of size, color, and shape was faster than judging the presence of size alone, shape alone, and combined size and shape (Fournier & C. W. Eriksen, 1991).

These findings suggest that judging the presence of two or more target features within an object can be faster and more accurate than judging the presence of the least discriminable of these target features alone. This phenomenon will be referred to as *multiple-feature benefits*. It is unclear as to how processing more information led to faster and more accurate responses. In order to make a "present" response in the three-feature judgments, one must determine whether a specific size, a specific shape, and a specific color are present. However, in order to make a "present" response in the one-feature judgments of size alone or shape alone, only one target feature must be determined.

These findings are inconsistent with simple serial or parallel feature processing models (see also findings by Lockhead, 1972, 1979, and Miller, 1978). Simple serial models predict that increasing the number of target features within an object should increase "present" response RTs. In other words, judging whether three specific features are present should take longer than judging whether only a single feature is present. This is because all three features must be determined, as opposed to only one feature, before a "present" response can be correctly executed (without guessing). Simple parallel models, in contrast, predict that judging the presence of three features should take as long as judging the presence of the slowest (least discriminable) of any one of these three features. Thus, "present" response latency would be limited by the target feature that has the slowest processing time.

In the present study, we examined the phenomenon of multiple-feature benefits. We chose to evaluate feature processing within a single object because we could keep the visual stimulus constant and vary only the features within this stimulus that were relevant for a particular response. The ability of various information processing models to account for multiple-feature benefits is discussed.

EXPERIMENT 1

The purpose of Experiment 1 was twofold. First, it was designed to test the assumptions of simple serial and parallel models, which do not predict multiple-feature benefits. Second, it was designed to determine whether multiple-feature benefits occur (1) when only a single object is presented, (2) when the location of the object is constant, and (3) when the target feature or combination of target features varies across trials. The discrimination difficulty of the three different target features (color, shape, and size) within a letter varied as described in the preliminary experiment. Speeded two-choice responses were made that indicated whether the target features were present or absent.

Method

Subjects. Four male and 4 female undergraduates at the University of Illinois served as paid volunteers. All were right-handed, and all reported having normal or corrected-to-normal vision.

Apparatus and Stimuli. Stimuli were presented on a computer monitor. In order to keep stimulus distance constant across subjects, the subjects viewed the stimuli through a face mask. A white fixation cross measuring 0.20° of visual angle appeared in the center of the monitor before and during each trial.

The letter probe appeared 0.37° of visual angle above the fixation cross. The features of the letter probe varied on three different dimensions: shape (S or C), size (large or small), and color (red or green). The large letters and the small letters were, respectively, 0.33° and 0.27° of visual angle in height (a 22% size difference). Luminance for green-colored letters was 13.7 cd/m^2; luminance for red-colored letters was 9.6 cd/m^2.

A written message indicating the target features to be judged appeared in the upper left half of the monitor. When letter shape was a target, the actual letter character appeared in the message, because it could not be spelled out. In addition, when letter shape was a target and the size of the letter was not, both the small and the large version of the letter character appeared in the message along with the word *or*.

The subject initiated each trial by pressing a hand button held in the left hand. He/she moved a hand lever with the right hand to the left or the right to indicate whether the specific target feature(s) was present or absent. The computer recorded response time (RT) and response accuracy.

Procedure. At the start of each trial, a message was displayed indicating which specific one, two, or three target features the subject was to judge as present or absent. This message was displayed until the subject pressed the hand button to clear the screen. After the screen was cleared, the subject saw a small circle 0.20° of visual angle in the center 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. The subject initiated each trial by pressing the hand button when the fixation cross was in clear focus. Immediately after pressing the hand button, the letter probe appeared above the fixation cross for a duration of 50 msec.

The subjects judged whether the target features were present or absent. 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. Half of the subjects moved the hand lever to the right when the target feature(s) was present and to the left when the target feature(s) was absent. The other half of the subjects had the opposite hand-lever response assignment. The subjects were instructed to respond as quickly and as accurately as possible. "Present"/"absent" response direction was held constant for each subject.

Target features varied across trials. There were three possible one-feature judgments (color, size, and shape), three possible combinations of two-feature judgments (shape and color, shape and size, color and size), and one combination of three-feature judgments (size, color, and shape). The eight possible letter probes resulting from the color, size, and shape features were run within subjects, and the specific target color, shape, and/or size to be judged (target feature combinations) were run between subjects. The eight possible target feature combinations were as follows: *large green S, small green S, large green C, small green C, large red S, small red S, large red C*, and *small red C*. In order to minimize response competition between trials, each subject was assigned to one of the above target feature combinations. Thus, each subject was asked to make "present" judgments for only one specific target feature combination.

The subjects received 16 practice trials in which the color, shape, and size of the letter probe were verbally reported. Those who exceeded four errors in this task were excused from the experimental sessions.

The subjects completed two experimental sessions consisting of eight blocks of 74 trials each. Each block consisted of 24 one-feature judgments, 36 two-feature judgments, and 14 three-feature judgments. On half of each of the feature judgment trials, the probe contained the specific target features; on the other half of the trials, the probe did not. The specific target features and the presence/absence of the target features occurred randomly within a block.

Data analysis. Mean correct RTs and percent accuracy were analyzed. Repeated measures analysis of variance (ANOVAs) were performed on the factors of response type (2 levels: "present" and "absent") and feature judgment (7 levels: size, shape, color, size and shape, size and color, color and shape, and three-feature). In addition, repeated measures ANOVAs were conducted on correct "absent" response trials for each of the two-feature judgments and the three-feature judgments based on which target features were present in the object [target feature(s) present]. The levels of the target feature(s) present factor were as follows: the two-feature size and shape judgment had three levels (shape, size, and none); the two-feature size and color judgment had three levels (color, size, and none); the two-feature color and shape judgment had three levels (color, shape, and none); the three-feature judgment had seven levels (color and shape, size and color, size and shape, color, shape, size, and none).

Results and Discussion

As shown in Figure 1, multiple-feature benefits occurred for "present" responses. Also, somewhat weaker multiple-feature benefits were found for "absent" responses. A repeated measures ANOVA (block [8] × ses-

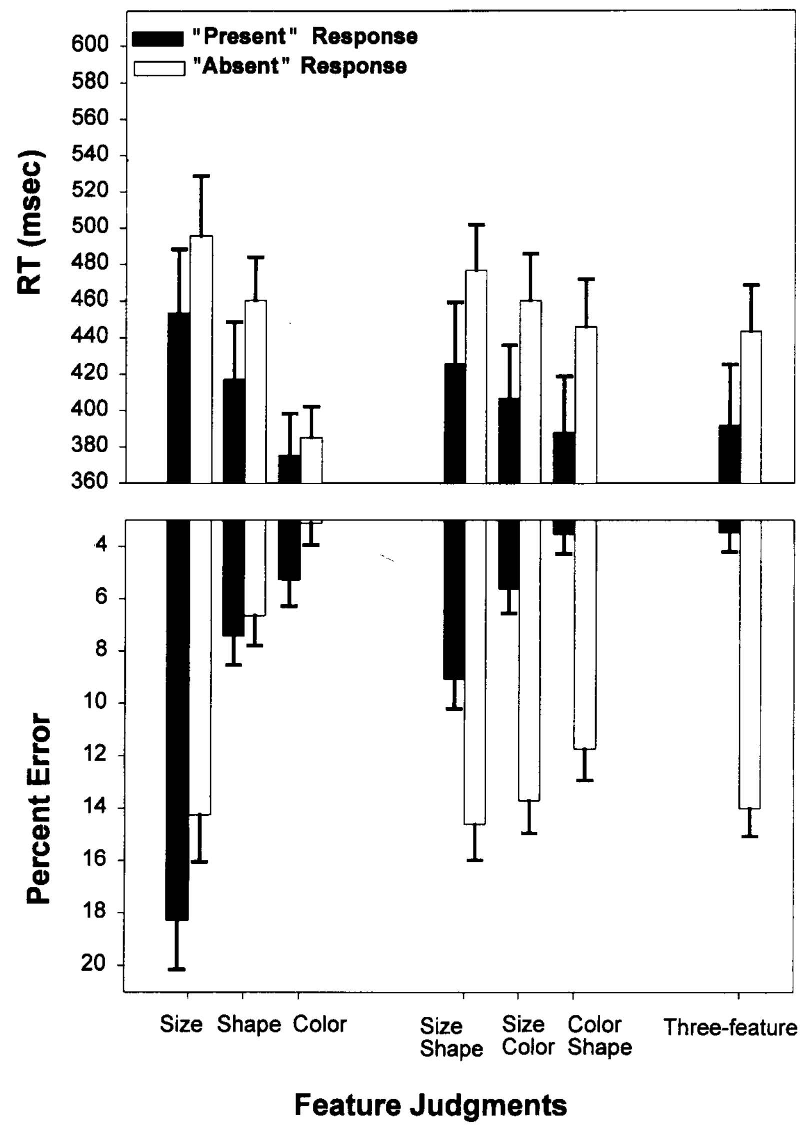

Figure 1. RTs and percent errors for "present" and "absent" responses for each of the feature judgments in Experiment 1.

sion [2] × response type [2] × feature judgment [7]) was conducted on both correct mean RTs and accuracy. All significant effects for RTs and accuracy are presented in Table 1.

Practice effects. The main effects and interactions involving session and block for RT and accuracy indicated that feature judgment performance improved with practice. In addition, the session × feature judgment interaction for RT indicated that the decrease in RT across sessions was smaller for the color-alone judgment than for the other feature judgments (25 msec vs. approximately 45 msec; Tukey, $p < .05$). This finding suggests that the very fast RTs for the color-alone judgment was limited by a floor effect in Session 2. Also, the session × feature judgment interaction for accuracy indicated that the errors for the size-alone judgment decreased more (by 2%) relative to the shape and two-feature size and color judgment (Tukey, $ps < .05$). More importantly, multiple-feature benefits were found for "present" responses in the first block of trials in Session 1 (see Table 2), even though the subjects received only 16 practice trials. This finding suggests that multiple-feature benefits are not dependent on practice effects. Because feature judgments for "present" and "absent" responses did not vary across sessions, session effects are not discussed further.

Figure 1 shows that as the discriminability of the target features increased, RT and errors decreased (main effect of feature judgment). As predicted, "present" and "absent" RTs among the one-feature judgments were fastest and most accurate for color, slowest and least accurate for size, and intermediate in speed and accuracy for shape [for RT, planned $F(1,7) > 9.0 < 20.0, p < .05$; for accuracy, planned $F(1,7) > 4.20 < 19.90, p < .07$]. In addition, "absent" responses were slower than "present" responses (main effect of response), and "absent" responses became even slower and less accurate relative to "present" responses as the number of target features increased (response × feature judgment). Because trends across feature judgments varied between "present" and "absent" responses, these trends were evaluated within each response type by planned F comparisons, with 1 and 7 degrees of freedom (dfs).

"Present" responses. As predicted, multiple-feature benefits were found for "present" responses and were dependent on the combination of target features (see Figure 1). When the subjects were required to judge the presence of a conjunction of features, in which one feature was relatively difficult to discriminate (e.g., size) and one or more features were relatively easy to discriminate (e.g., color and/or shape), their RTs were faster and more accurate than when they judged the presence of the less discriminable feature alone (e.g., size). More specifically, "present" responses for the two-feature size and color and two-feature size and shape judgments were faster (by 46 and 26 msec, respectively) and more accurate than the size-alone judgment ($ps < .05$). Also, the two-feature color and shape judgment was faster (by 29 msec) and more accurate than the shape-alone judgment (for RT, $p < .05$; for accuracy, $p = .056$). Moreover, the three-feature judgment was faster than the size-alone, shape-alone, and two-feature size and shape judgments (61, 25, and 34 msec faster, respectively; $ps < .05$). The three-feature judgment was also more accurate than the size-alone and two-feature size and shape judgments ($ps < .01$). There was no significant RT and accuracy difference between the three-feature and two-feature size and color judgments ($ps > .08$) or the two-feature color and shape judgment (Fs < 1). As shown in Figure 1, error data indicate that the RT effects were not due to a speed–accuracy tradeoff.

"Absent" responses. Figure 1 shows that multiple-feature benefits for "absent" responses were not as large as those found for "present" responses. Also, as previously mentioned, "absent" responses were substantially slower and less accurate than "present" responses for the two-feature and three-feature judgments, relative to the one-feature judgments. This might have been due to decision competition (Proctor, 1981) or response competition (B. A. Eriksen & C. W. Eriksen, 1974); this is possible because sometimes one or more target features were present in the object when an "absent" response was required in the multiple-feature judgments. For example, "absent" responses were required in the three-feature judgments when the letter probe contained one target feature that was absent and two target features that were present, when the letter probe contained two target features that were absent and one target feature that was present, and when all three target features were absent.

Perhaps the target feature(s) present within the object activated the "present" response, which, in turn, interfered with activation of the "absent" response. This idea is consistent with the concept of response competition (e.g., see Coles, Gratton, Bashore, C. W. Eriksen, & Donchin, 1985; B. A. Eriksen & C. W. Eriksen, 1974; Miller,

Table 1
Correct Response Time and Accuracy ANOVA Tables for Significant Effects in Experiment 1

Factor	Significance	MS_e
	Response Time	
response	$F(1,7) = 8.66, p < .05$	88,169
feature	$F(6,42) = 26.62, p < .001$	8,374
session	$F(1,7) = 22.57, p < .001$	43,518
block	$F(7,49) = 9.82, p < .001$	7,244
session × block	$F(7,49) = 6.23, p < .001$	5,229
session × feature	$F(6,42) = 3.47, p < .01$	2,260
block × feature	$F(42,294) = 1.56, p < .05$	1,751
response × feature	$F(6,42) = 5.96, p < .001$	3,360
	Accuracy	
response	$F(1,7) = 6.57, p < .05$	.0900
feature	$F(6,42) = 8.96, p < .001$	.0425
block	$F(7,49) = 2.61, p < .05$	.0191
session × feature	$F(6,42) = 2.71, p < .05$	.0154
response × feature	$F(6,42) = 7.51, p = .001$	.0289
session × block	$F(7,49) = 2.70, p < .05$	.0176

Note—feature = feature judgment.

Table 2
Feature Judgments for "Present" Responses in the First Block of Trials in Experiment 1

	Feature Judgments						
	size	shape	color	size & shape	size & color	color & shape	three-feature
Reaction time (msec)	465	464	379	459	457	414	418
Errors (%)	25	9	0	21	25	17	11

1991). To evaluate this possibility, repeated measures ANOVAs (letter probe × target feature[s] present) were conducted on correct "absent" RTs and accuracy separately for the three-feature judgments and each of the two-feature judgments. Figures 2 and 3 show "absent" RTs and accuracy relative to which target features were present in the object for the three-feature and two-feature judgments, respectively.

These data show that when the most discriminable feature (i.e., color) was present, "absent" response performance suffered most in both the three-feature and the two-feature judgments. There was a main effect of target

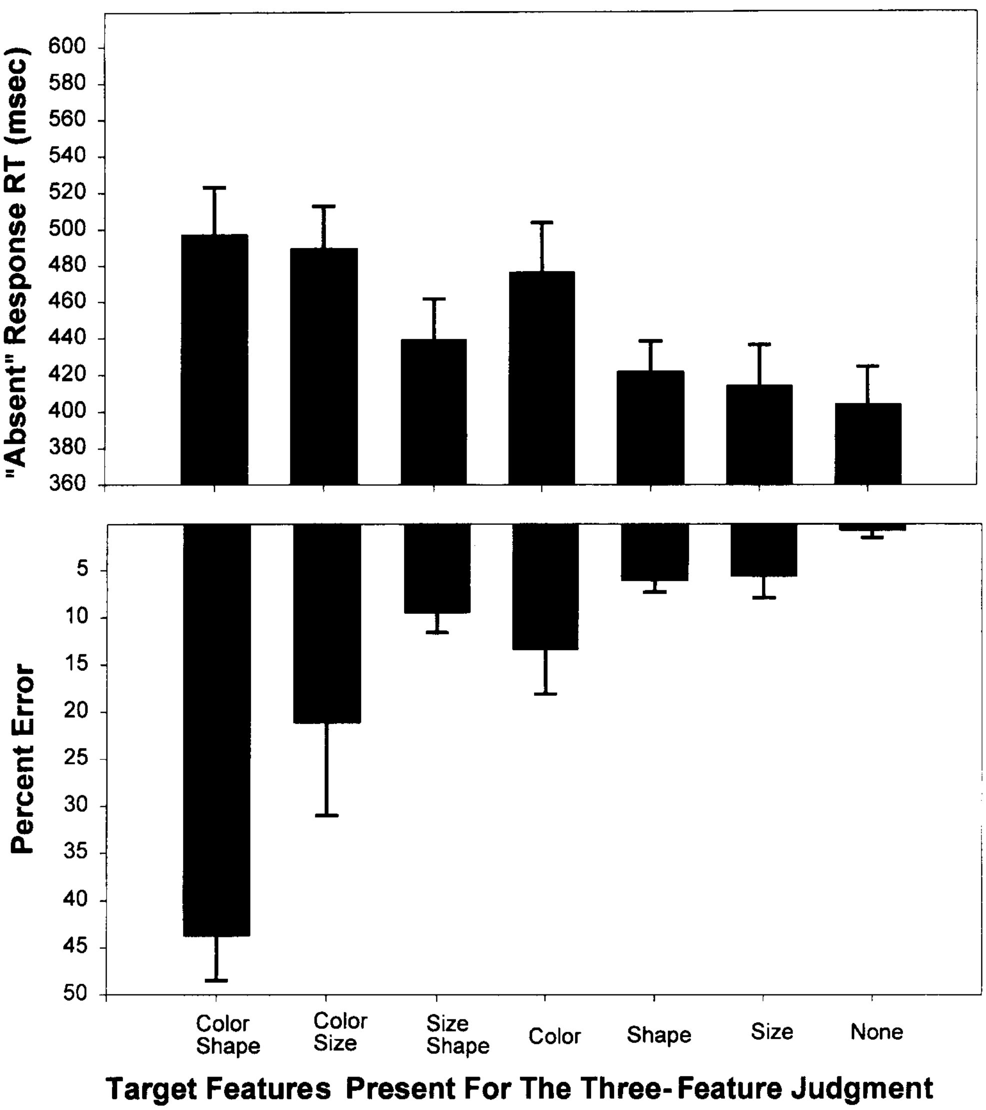

Figure 2. Correct "absent" response RTs and percent errors according to which target features were present in the three-feature judgment condition in Experiment 1.

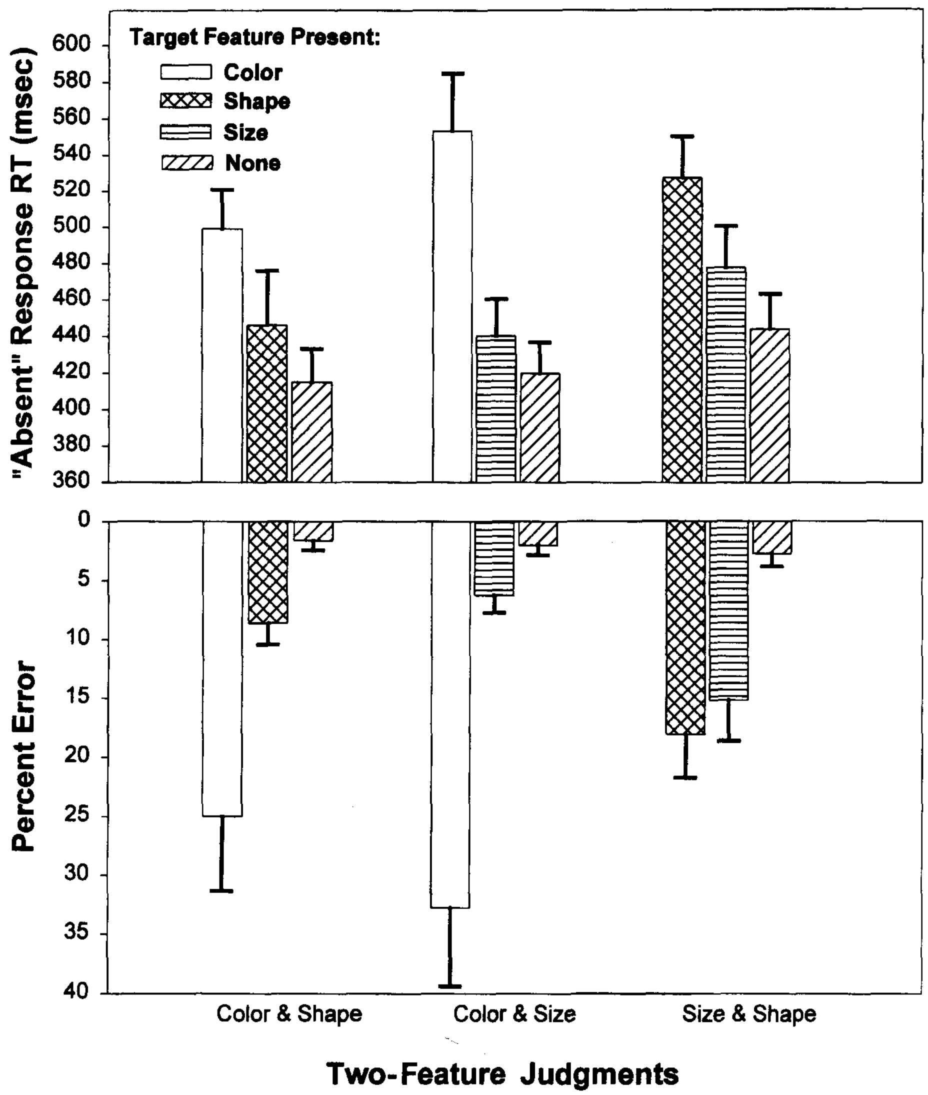

Figure 3. Correct "absent" response RTs and percent errors according to which target features were present in each of the two-feature judgments in Experiment 1.

features present for both RT and accuracy for the three-feature judgment [for RT, $F(6,42) = 14.04$, and for accuracy, $F(6,42) = 2.43$, $ps < .05$], the two-feature shape and size judgment [for RT, $F(2,14) = 20.32$, and for accuracy, $F(2,14) = 30.85$, $ps < .001$], the two-feature color and size judgment [for RT, $F(2,14) = 37.65$, and for accuracy, $F(2,14) = 19.59$, $ps < .001$], and the two-feature color and shape judgment [for RT, $F(2,14) = 13.39$, and for accuracy, $F(2,14) = 9.55$, $ps < .01$]. Significant trends for the feature judgments were evaluated by planned F comparisons, with 1 and 7 *dfs*.

Significant trends for the three-feature judgments were as follows. When one of the three target features was present, "absent" responses were slower when this feature was color relative to when it was shape or size ($ps < .01$). When two of the three target features were present, "absent" responses were slower when these features were color and shape or color and size relative to when they were size and shape ($ps < .001$). Errors tended to decrease as RT decreased, indicating that the above RT interpretations were not due to a speed–accuracy tradeoff.

Similar results were found for the two-feature judgments. "Absent" responses were slower ($ps < .01$) and less accurate ($ps < .064$) for the two-feature size and shape and two-feature color and size judgments when the more discriminable target feature (i.e., color or shape) was present and the less discriminable feature (i.e., size) was absent. In addition, "absent" responses were slower and less accurate for the two-feature color and shape judgment when the more discriminable feature (i.e., color) was present and the less discriminable feature (i.e., shape) was absent ($ps < .05$). Finally, "absent" responses for the two-feature judgments were overall fastest ($ps < .05$) and most accurate ($ps \leq .064$) when none of the target features were present.

These results show that increasing the discriminability of target features present in the object reduced the speed and accuracy of the correct "absent" response (multiple-feature costs). This finding suggests that decision or response competition often occurred in the multiple-feature judgments when an "absent" response was required.

Summary. Multiple-feature benefits were found for "present" responses when an object was presented alone, at a constant location, and when the target features changed across trials. These results also showed that discrimination performance was dependent on the discriminability of target features that were present in the object. When the discriminability of target features present in the object increased, correct "present" responses were faster and more accurate, whereas "absent" responses were slower and less accurate.[1]

Multiple-feature benefits are not consistent with simple serial and parallel models. However, it is possible that benefits are based on decision (e.g., Proctor, 1981; Ratcliff, 1978) or response priming (e.g., Miller, 1982a). This is possible because the "absent" response data suggest that decision or response competition played a role in multiple-feature costs. Before these possibilities are considered, the robustness of multiple-feature benefits and costs, as well as other possible explanations, will first be examined.

Recall that, in Experiment 1, the specific target features were run between subjects. In addition, the specific letter probes requiring a "present" response occurred more frequently as the number of target features increased. For example, when one feature was a target, four of the probes contained this feature, and each was presented one eighth of the time. When two features were targets, the two probes that contained these two features were presented one fourth of the time. Finally, when three features were targets, the probe that contained these three features was presented half of the time. Thus, the letter probe matching the assigned three-feature target was presented twice as often as any of the other letter probes. It has been shown (see Nickerson, 1972, 1973) that increased frequency of presentation of a particular stimulus (letter probe) can facilitate RT to this stimulus.

EXPERIMENT 2

The purpose of Experiment 2 was to determine whether multiple-feature benefits are obtained when all possible features and combination of features are discriminated and when the frequency of each letter probe mapped to the "present" response is equated across the one-, two-, and three-feature judgments. In order to balance the frequency without markedly increasing the number of trials, the letter probes that did not contain any target features were not presented in the multiple-feature judgments. As a result, the total number of multiple-feature judgment trials was reduced, relative to Experiment 1. However, we expected to find benefits if they were not linked to probe presentation frequency differences across the feature judgments.

Method

Subjects. One male and 7 female undergraduate and graduate students from the University of Illinois served as paid volunteers. All subjects reported having normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure. The apparatus, stimuli, and procedures were identical to those in Experiment 1, with the following exceptions. First, the message indicating which features were targets was in a font different from that of the letter probe. Second, each subject judged the presence or absence of each possible one-, two-, and three-feature combination. Third, the presentation frequency of each possible letter probe requiring a "present" response was balanced across the one-, two-, and three-feature judgments.

The eight possible letter probes were presented five times each within each feature judgment in a session. Thus, each of the six one-feature judgments contained 40 letter probe presentations with a "present":"absent" response ratio of 20:20, each of the 12 two-feature judgments contained 20 letter probe presentations with a "present":"absent" response ratio of 10:10, and each of the eight three-feature judgments contained 10 letter probe presentations with a "present":"absent" response ratio of 5:5.

In order to equate "present" and "absent" responses across feature judgments, some letter probes were removed. In the two-feature judgments, the two letter probes that did not contain either target feature were not presented. For example, if the target features were *red S*, then letter probes with a different color and shape were not presented. In the three-feature judgments, two letter probes were not presented: the letter probe that did not contain any of the three target features, and the letter probe whose color and shape were different from the target color and shape.

Each experimental session consisted of one block of 560 trials (80 trials of three-feature, 240 trials of two-feature, and 240 trials of one-feature judgments). The subjects received 55 practice trials in the first session. They took short breaks at 10-min intervals and when fatigued.

Results and Discussion

Practice effects. A repeated measures ANOVA (session [2] $\times$ response [2] $\times$ feature judgment [7]) was performed on mean correct RTs and accuracy. All significant effects were similar to those in Experiment 1. There was a main effect of session for RTs [$F(1,7) = 36.85, p < .001$] and accuracy [$F(1,7) = 6.47, p < .05$] and a session $\times$ feature judgment interaction for RTs [$F(6,42) = 3.0, p < .05$]. Responses were overall faster and more accurate in Session 2 than in Session 1. In addition, RTs decreased more for the multiple-feature judgments (70 msec) than for the one-feature judgments (40–50 msec) in Session 2. The above findings, along with the finding that there was no significant difference between "present" and "absent" responses across sessions, indicate that the 55 practice trials were not sufficient for the subjects' to learn all possible target–response mappings, especially when discriminating multiple features. It might have taken much longer to learn the response mappings in Experiment 2 than in Experiment 1 since responses were based on all possible target feature combinations, which varied across trials. For this reason, only Session 2 was analyzed.

"Present" and "absent" responses across the different feature judgments are presented in Figure 4. Similar to

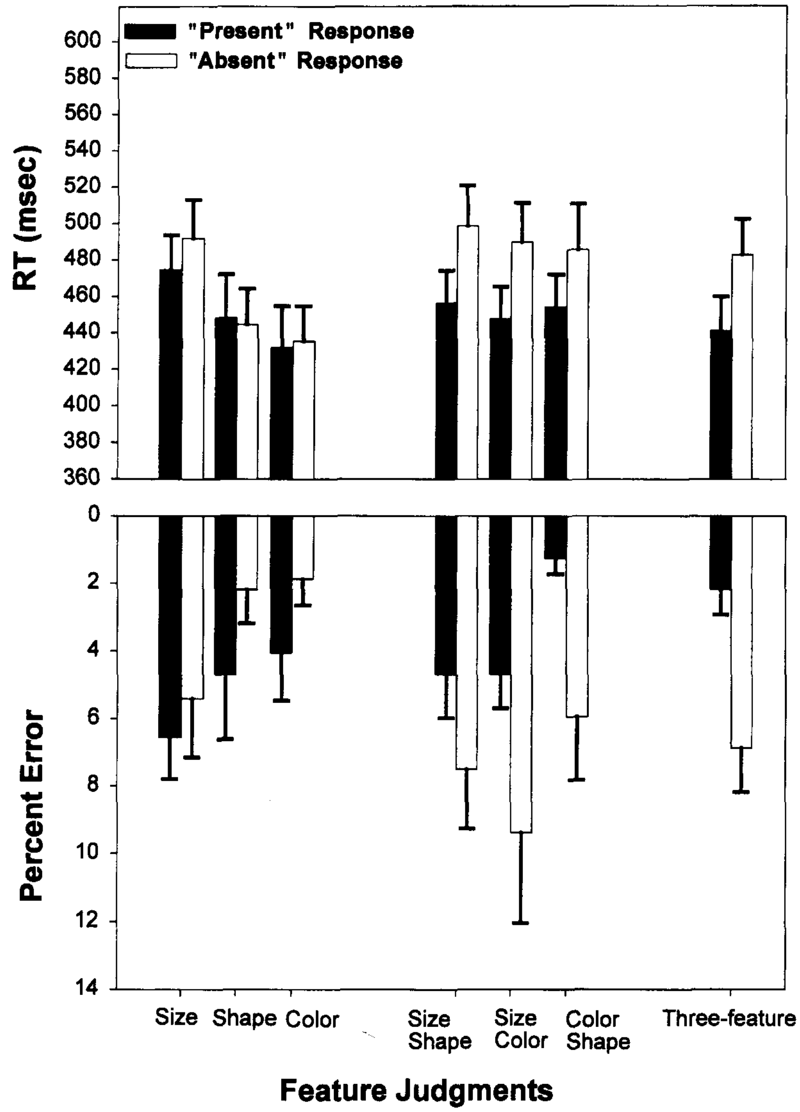

Figure 4. RTs and percent errors for "present" and "absent" responses for each of the feature judgments in Experiment 2.

Experiment 1, multiple-feature benefits were found for "present" responses; however, these benefits were somewhat weaker. A repeated measures ANOVA (response [2] × feature judgment [7]) was performed on both mean correct RTs and accuracy in Session 2. All significant effects for RTs and accuracy were similar to those found in Experiment 1, and these effects are presented in Table 3.

As shown in Figure 4, "present" and "absent" response RTs and accuracy among the one-feature judgments were not significantly different between color and shape (planned Fs < 1). This finding suggests that color and shape did not differ in discriminability, which is inconsistent with the one-feature judgment trends found in Experiment 1. However, both RT and accuracy for color-alone and shape-alone judgments were faster and more accurate than the size-alone judgments [planned $F(1,7) > 6.20$, $ps < .05$, for both RT and accuracy]. This indicates that similar to Experiment 1, size was the least discriminable feature. Because the trends across feature judgments varied between "present" and "absent" responses (response × feature judgment), they were evaluated within each response type by planned F comparisons, with 1 and 7 *df*s.

"Present" responses. As is evident in Figure 4, multiple-feature benefits were found for "present" responses. In general, when the subjects judged the presence of a conjunction of features, in which one feature was relatively difficult to discriminate and one feature was relatively easy to discriminate, their RTs were often faster and/or more accurate than when they judged the presence of the less discriminable feature alone.

Table 3
Correct Response Time and Accuracy ANOVA Tables for Significant Effects in Experiment 2

Factor	Significance	MS_e
	Response Time	
response	$F(1,7) = 5.24, p = .056$	3,328
feature	$F(6,42) = 11.30, p < .001$	432
response × feature	$F(6,42) = 4.71, p < .001$	319
	Accuracy	
feature	$F(6,42) = 3.98, p < .01$	.0157
response × feature	$F(6,42) = 2.78, p < .05$	.0266

Note—feature = feature judgment.

Although these benefits were not as strong as those found in Experiment 1, the results, including the insignificant data trends, are consistent with Experiment 1. More specifically, the two-feature size and color judgment was significantly faster (27 msec) than the size-alone judgment ($p < .01$). In addition, the three-feature judgment was faster (34 msec) and more accurate than the size-alone judgment ($p = .06$, and $p < .01$, respectively). However, the three-feature judgment was not significantly faster (only 6–7 msec faster) than the two-feature size and shape judgment and the two-feature size and color judgment, but the three-feature judgment was significantly more accurate ($ps < .05$). This finding suggests that a benefit existed for the three-feature judgment, relative to these two-feature judgments. Also, the two-feature size and shape judgment was not significantly faster (19 msec) than the size-alone judgment ($p = .09$), but the trends were consistent with those in Experiment 1. Unlike in Experiment 1, however, responses for the three-feature and two-feature color and shape judgments were no different from those for the shape-alone judgment (Fs < 1).

Significant multiple-feature benefits were found only for feature judgments in which size was a target feature. The lack of significant differences found between the color-alone and shape-alone judgments ($F < 1$) might have contributed to the lack of multiple-feature benefits found for the three-feature and two-feature shape and color judgments relative to the shape-alone judgment.

"Absent" responses. Similar to Experiment 1, multiple-feature costs were found for "absent" responses. Figures 5 and 6 show the relationship between correct "absent" responses (RTs and accuracy) and the target features present in the object for the three-feature and two-feature judgments, respectively. Because there were very few observations per cell in this analysis, "absent" response data from both experimental sessions were used ($ns = 2$ and 5 maximum observations per cell for the three-feature and two-feature judgments, respectively). Repeated measures ANOVAs (letter probe × target feature[s] present) were conducted on correct "absent" RTs and accuracy separately for the three-feature judgment and each of the two-feature judgments.

As shown in Figures 5 and 6, "absent" RTs and errors decreased as the number and discriminability of target features present increased. There was a main effect of target features present for both RTs and accuracy in the three-feature judgment [$F(4,28) = 12.81, p < .001$, and $F(4,28) = 2.65, p = .054$, respectively] and in the two-feature size and color judgment [$F(1,7) = 32.14, p < .001$, and $F(1,7) = 15.29, p < .01$, respectively]. There was also a main effect of target features present for RTs in the two-feature size and shape judgment [$F(1,7) = 179.53, p < .001$]. In general, "absent" responses for these feature judgments were hindered when the most discriminable of the target features (i.e., color and/or shape) was present in the object and the least discriminable of the target features (i.e., size) was absent. There were no significant main effects found in the two-feature color and shape judgment, indicating that these features did not significantly differ in discriminability. There was also a significant letter probe × target feature(s) present interaction for accuracy [$F(7,49) = 2.25, p = .05$]; however, no interpretation is offered for this latter effect.

Summary. Similar to Experiment 1, increasing the number and discriminability of target features present in the object led to multiple-feature benefits for "present" responses and multiple-feature costs for "absent" responses. These results were found when all possible feature combinations were judged and the presentation frequency of a specific stimulus (letter probe) mapped to the "present" response was equated across the different feature judgments. The magnitude of benefits, however, was less than that found in Experiment 1. Significant benefits were found only when size was a target feature. The reduction in benefits (and costs) for the two-feature color and shape judgment relative to the shape-alone judgment might have been due to the insignificant difference in RTs and accuracy between the color target and shape target discriminations. Perhaps multiple-feature benefits do not occur if features are similar in discriminability. Note that, although stimuli were the same as those used in Experiment 1, this does not indicate that discrimination was constant between these two experiments because discriminability is subjective and will vary across observers.

One possible explanation for multiple-feature benefits is that the subjects strategically *weighted* their decisions on the more easily perceived target features (i.e., color and shape, but especially color) relative to the more difficult target feature (i.e., size). Thus, the least discriminable target feature (i.e., size), although not completely ignored during multiple-feature judgments, might not have been evaluated on each trial. Thus, benefits may be based on guesses leading to more false alarms for "present" responses.

This idea is consistent with the larger multiple-feature benefits and costs found in Experiment 1 relative to Experiment 2. First, "present" response error rates were high for the size-alone judgments and discrimination of the size feature benefited most when judged in combination

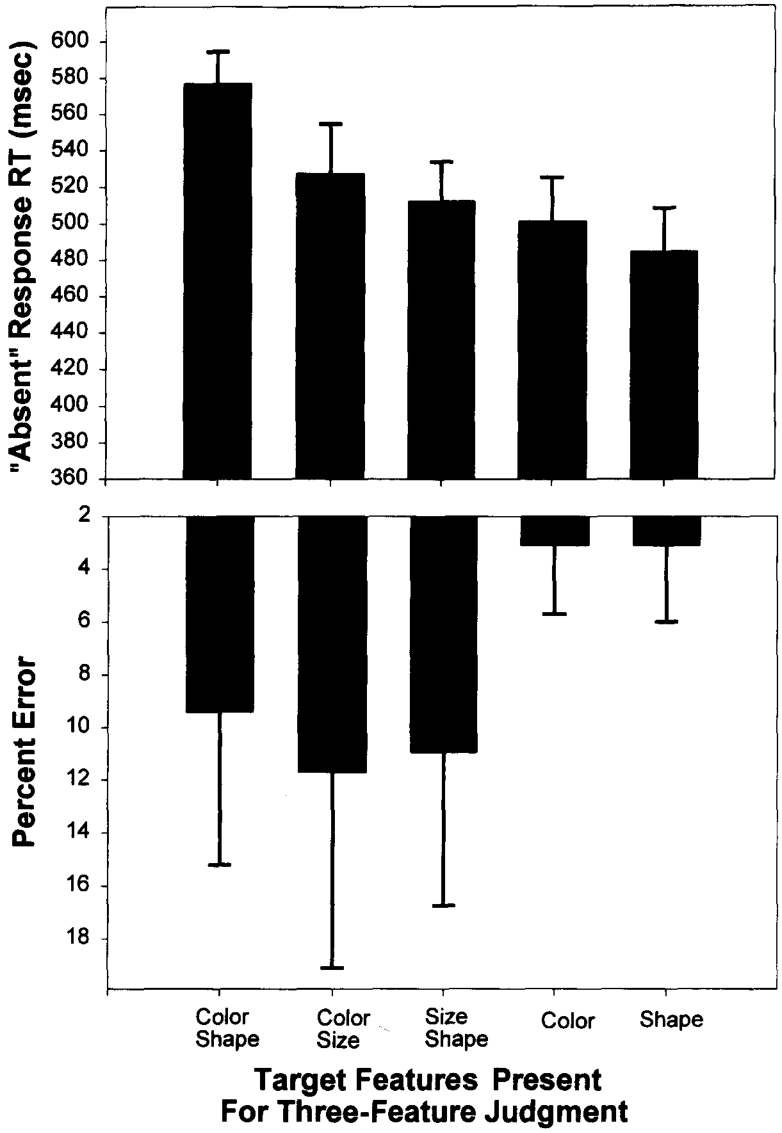

Figure 5. Correct "absent" response RTs and percent errors according to which target features were present in the three-feature judgment in Experiment 2.

with color and/or shape in Experiment 1. Second, these benefits were greater when "present" responses for the size-alone judgment had a higher error rate (20% in Experiment 1) as opposed to a lower error rate (7% in Experiment 2). Third, "absent" response error rates for the three-feature judgment was highest (44%) in Experiment 1 when only the target feature of size was mapped to the "absent" response.

EXPERIMENT 3

The purpose of Experiment 3 was threefold. The first goal was to determine whether multiple-feature benefits and costs are found when only the two features of color and shape serve as targets.

The second goal was to determine whether the less discriminable feature (i.e., shape) on a proportion of trials is ignored or weighted less than the more discriminable feature (i.e., color) when subjects make a "present" judgment based on two features. We evaluated this by adding two letters that flanked the target probe and varying the response relevance of the flanker features. These flankers contained features that were either response compatible or response incompatible with the target features (similar to the response-compatibility paradigm; B. A. Eriksen & C. W. Eriksen, 1974). For example, if the two-feature judgment was "red H" and the target probe was a *red H,* both flankers either were identical to the target probe (e.g., *red H*) or contained a different color (e.g., *green H*), a different shape (e.g., *red K*), or

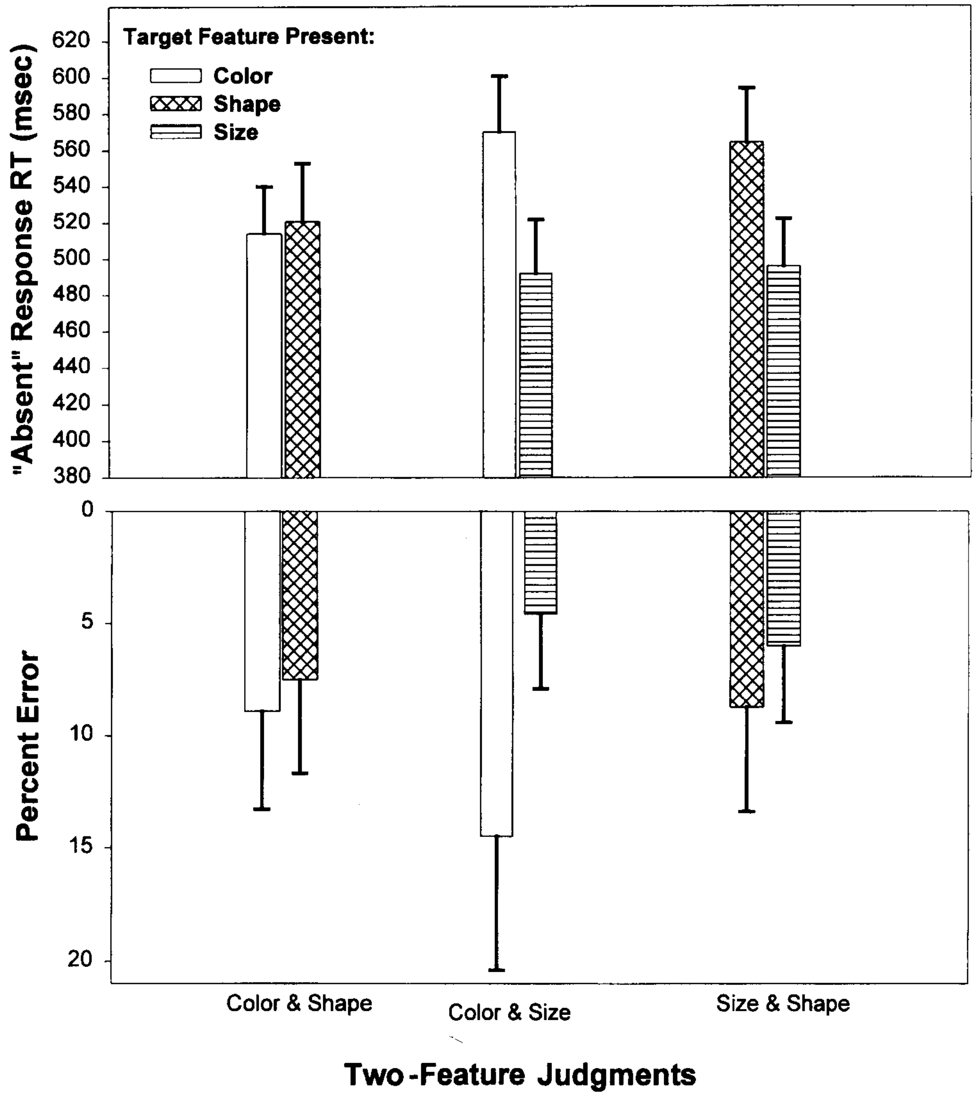

Figure 6. Correct "absent" response RTs and percent errors according to which target features were present in each of the two-feature judgments in Experiment 2.

a different color and shape (e.g., *green K*) than the target probe. If the shape feature was weighted less than color for the two-feature color and shape judgment, we should find less interference for "present" responses when the flanker shape does not match the two-feature judgment compared with when the flanker shape does not match the one-feature judgment. In the former case, shape may be less critical for the judgment (two thirds probability of correct "present" response based on color); in the latter case, the shape feature is critical for the judgment.

The magnitude of flanker interference can be used as a measure of feature weighting because attention can be drawn to stimuli on the basis of their task relevance or attentional set (e.g., Cave & Wolf, 1990; Duncan & Humphreys, 1989; Egeth & Yantis, 1997; Treisman & Gelade, 1980). Thus, if the flanker contains task-relevant information, attention will be drawn to the flanker on the basis of this information (see Johnston & Dark, 1986, for a review). Cohen and Shoup (1997) have also shown that target discrimination is delayed by a flanker if the flanker contains a task-relevant feature that is incompatible with the target feature of the to-be-attended target (probe). Task-irrelevant flanker features were shown not to interfere with target discrimination of the probe. The Cohen and Shoup findings suggest that attentional set can be based on specific features within objects (see also negative priming based on incompatible flanker attributes; Tipper, Weaver, & Houghton, 1994). Therefore, if attentional set is based on a single feature (i.e., color) on a proportion of trials, this attribute alone will influence selection on those trials. Also, if attentional set is biased for a particular feature (i.e., color), then the unbiased feature (i.e., shape) will have a lower selection weight and should be less likely to influence selection.

The third goal was to determine whether flanker interference is influenced by the discriminability of the flanker features that are incompatible with the target features contained in the probe. If so, this suggests that features of an irrelevant object are processed and interfere with responses to the target object on the basis of which features are task relevant and on the basis of the discriminability of these relevant features.

Method

Subjects. Nine male and 7 female undergraduates from Washington State University participated for optional research credit in a psychology course. All reported having normal color vision, and all had normal acuity as assessed by a Snellen chart.

Apparatus, Stimuli, and Procedure. The apparatus and stimuli were identical to those in Experiment 1, with the following ex-

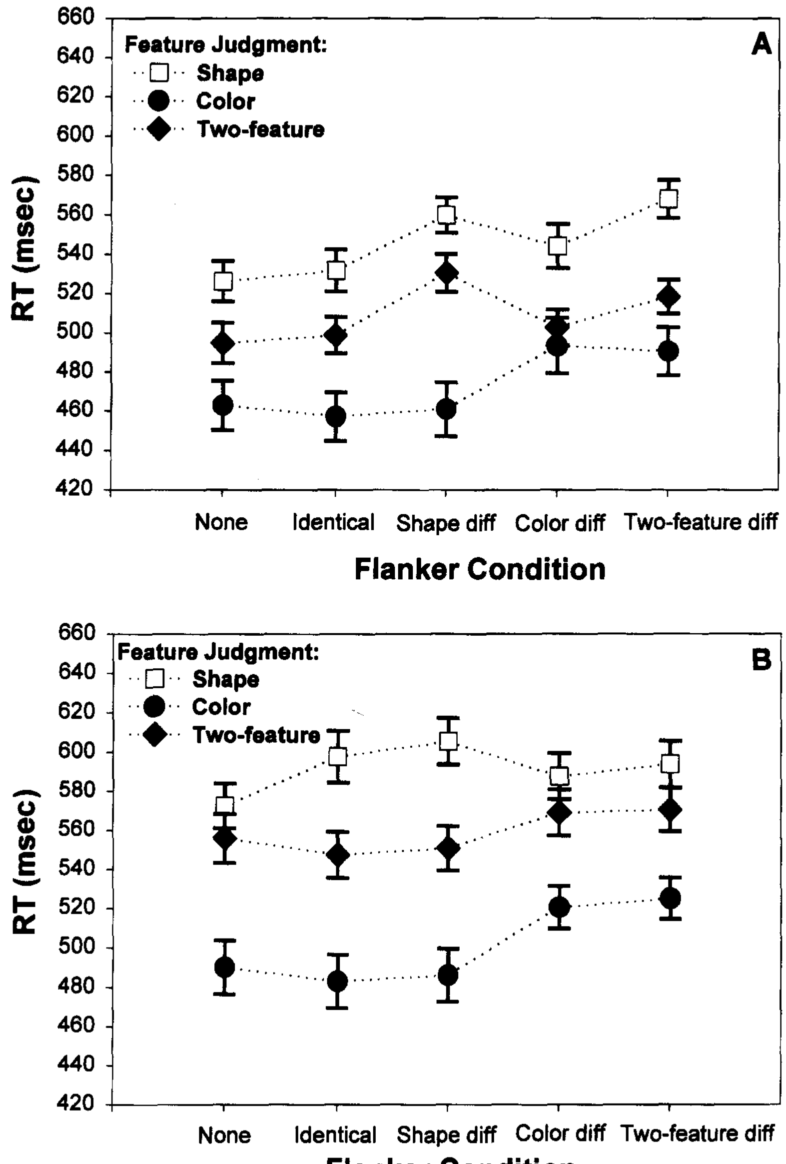

Figure 7. RTs for "present" responses (panel A) and "absent" responses (panel B) for each of the feature judgments across flanker conditions in Experiment 3. The levels of flanker conditions were as follows: none = no flanker; identical = flanker identical to probe; shape diff = flanker shape different from probe; color diff = flanker color different from probe; two-feature diff = both flanker features different from probe.

Table 4
Percent Errors for Each Feature Judgment Across Flanker Condition for "Present" and "Absent" Responses in Experiment 3

	Flanker Condition				
Feature Judgment	none	identical	shape diff	color diff	two-feature diff
	"Present" Response				
shape	6.94	10.94	8.19	9.50	3.25
color	4.19	6.88	4.06	7.81	8.94
two-feature	3.87	3.75	3.94	3.69	3.50
	"Absent" Response				
shape	7.00	9.31	11.75	8.13	10.00
color	3.50	2.88	3.13	4.88	6.19
two-feature	7.06	7.93	11.00	9.00	9.19

ceptions. The target probe could appear in any one of eight locations on an imaginary circle centered around the fixation cross. Two white dashes (0.6° center-to-center cue–target distance) were used as precues for target location and were presented 150 msec before the appearance of the target. In addition, noise letters (flankers) could appear simultaneously with the target probe at 1.15° of visual angle to the left and right of the target probe. Target probe and flankers appeared for 50 msec, 1.57° from the fixation cross. The target probe and flankers were either Hs or Ks colored in red or green. The flanker factor had five levels: (1) no flanker (*none*), (2) flanker identical to target (*identical*), (3) flanker shape different from target (*shape diff*), (4) flanker color different from target (*color diff*), and (5) flanker color and shape different from target (*two-feature diff*). At the start of each block, a message displayed which one or two target features to discriminate in the cued location.

The subjects completed a total of four sessions consisting of 12 blocks (4 blocks of each feature judgment). The first session was practice and was not included in the data analyses. Feature judgments (color, shape, color, and shape) were blocked, and block order was counterbalanced across sessions within and between subjects. The one-feature color and shape judgment blocks contained 40 trials, and the two-feature judgment blocks contained 60 trials. Target probe location and flanker condition occurred equally often in a random order within blocks.

Results and Discussion

Figure 7 shows the RTs for each feature judgment across flanker condition for "present" responses (panel A) and "absent" responses (panel B). Table 4 contains the percent errors for these factors. A repeated measures ANOVA (response [2] × feature judgment [3] × flanker [5]) was conducted on mean correct RTs and accuracy.[2] All significant effects for RTs and accuracy were consistent with those found in Experiments 1 and 2 and are presented in Table 5.

As shown in Figure 7 and Table 4, multiple-feature benefits were found for both "present" and "absent" responses (main effect of feature judgment). Specifically, RTs were faster and more accurate for the color and shape judgment (*M*s = 534 msec and 6.3%, respectively) than the shape-alone judgment (*M*s = 569 msec and 9.1%, respectively) [for RT, planned $F(1,15) = 123.55, p < .001$; for accuracy, $F(1,15) = 30.10, p < .001$]. This finding demonstrates that the multiple-feature benefits found in Experiments 1 and 2 were not dependent on the inclusion of the size feature judgment. In addition, it suggests that multiple-feature benefits are not dependent on extremely high error rates for the less discriminable feature. "Present" response error rates were 6%, 9%, and 4%, and "absent" response error rates were 4%, 9%, and 9%, for the color-alone, shape-alone, and two-feature judgments, respectively.

Also consistent with Experiments 1 and 2, the difference between "present" and "absent" responses was greater for the two-feature judgment than for the shape-alone and color-alone judgments (response × feature judgment). This finding is consistent with the idea that response or decision competition occurred on a proportion of trials, inflating RTs and errors for the two-feature "absent" responses. This finding is analyzed further in the section on multiple-feature costs below.

Furthermore, the flanker features influenced target feature RT and accuracy. As shown in Figure 7, the RT effect of flanker was similar for "present" and "absent" responses for the color-alone judgments, but the pattern was quite different across response types for the shape-alone and two-feature judgments (response × feature judgment × flanker interaction). These patterns were evaluated separately for "present" and "absent" responses by planned *F* comparisons, with 1 and 15 *df*s.

"Present" responses. As predicted, the flanker features that were different from the target features contained in the probe interfered with target feature discrimination (see Figure 7, A). The color-alone judgment was 31 msec slower when the flanker color was different from the target probe (color diff), relative to when no flanker was present (none) ($p < .01$). Also, the shape-alone judgment was 33 msec longer when the flanker shape was different from the target probe (shape diff), relative to when no flanker was present (none) ($p < .001$). Similarly, the two-feature judgment was 36 msec longer when the flanker shape was different from the target probe (shape diff), relative to when no flanker was present (none) ($p < .001$);

Table 5
Correct Response Time and Accuracy ANOVA Tables for Significant Effects in Experiment 3

Factor	Significance	MS_e
	Response Time	
response	$F(1,15) = 63.90, p < .001$	3,152
feature	$F(2,30) = 119.40, p < .001$	2,254
flanker	$F(4,60) = 39.41, p < .001$	324
response × feature	$F(2,30) = 7.75, p < .01$	684
response × flanker	$F(4,60) = 3.85, p < .01$	306
feature × flanker	$F(8,120) = 14.94, p < .001$	242
response × feature × flanker	$F(8,120) = 7.17, p < .001$	217
	Accuracy	
feature	$F(2,30) = 34.34, p < .001$	.0020
flanker	$F(4,60) = 3.42, p < .05$	.0017
response × feature	$F(2,30) = 24.49, p < .001$	.0020
feature × flanker	$F(8,120) = 2.16, p < .05$	.0019

Note—feature = feature judgment.

however, when the flanker color was different from the target probe (color diff), RTs were not significantly increased (only 8 msec; $p = .09$). Finally, the two-feature judgment was 24 msec longer when both color and shape flanker features were different from the target probe (two-feature diff), relative to when no flanker was present (none) ($p < .001$). The error data in Table 4 indicate that these RT effects were not due to a speed–accuracy tradeoff.

As predicted, both the shape-alone and the two-feature judgments were similarly slowed (relative to the no-flanker condition) when the flanker shape was different from the target probe. That is, when the flanker had a different shape from the target probe, and shape was one of the target features, RTs were slowed 36 msec for the two-feature judgment and 33 msec for the shape-alone judgment. This finding indicates that the shape discrimination was not weighted differently in these two judgments. Also, error RTs showed no evidence that responses were based on fast guesses for the two-feature judgment. Error RTs overall were slower than correct RTs, and the pattern across feature judgments was similar to correct RTs. Mean error RTs were 501, 572, and 551 msec, for color, shape, and two-feature judgments, respectively. Thus, multiple-feature benefits were not dependent on decreased weighting of the less discriminable feature (i.e., shape) in the two-feature judgments.

"Absent" responses. As predicted, the flanker interfered with target feature discrimination within the probe when the flanker contained the target features and the probe did not. Figure 7B and Table 4 show that when the flanker features differed from the probe, discrimination performance decreased, relative to when no flanker (none)

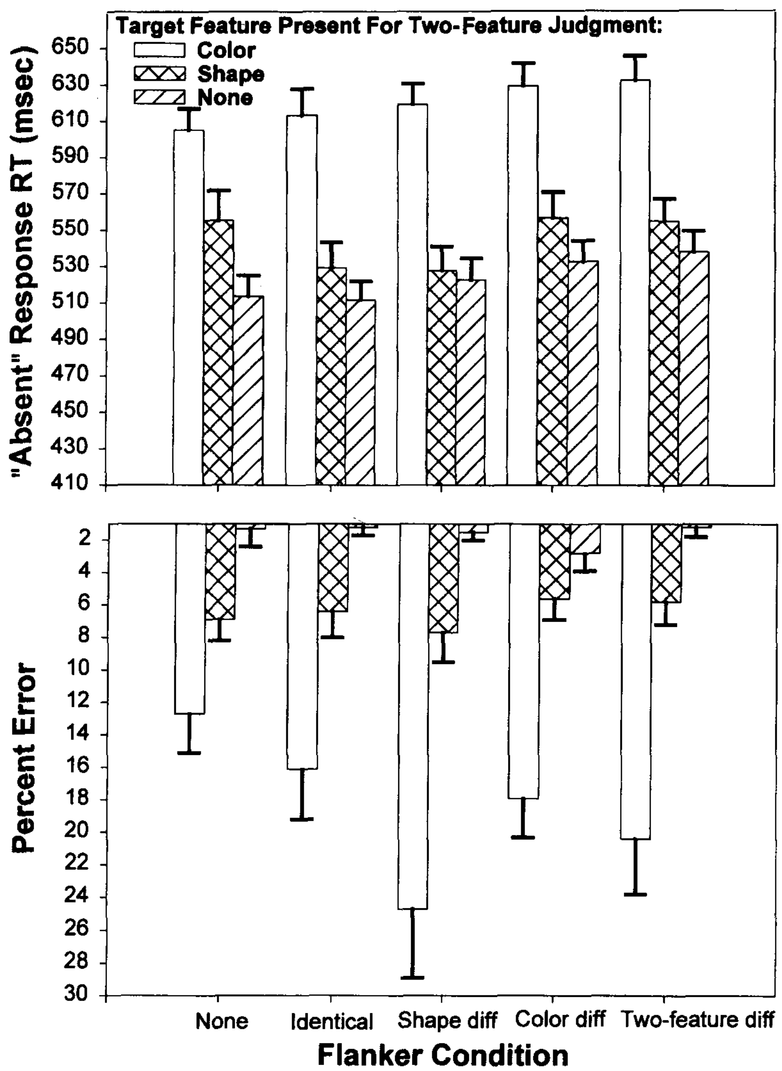

Figure 8. Correct "absent" response RTs and percent errors across flanker condition according to which target features were present in each of the two-feature judgments in Experiment 3.

was present. First, the color-alone judgment was 30 msec longer (no effect on accuracy) when the flanker color differed from the target probe (color diff) ($p < .001$). Second, the shape-alone judgment was 33 msec longer and was less accurate when the flanker shape differed from the target probe (shape diff) ($ps < .01$). Third, the two-feature judgment was 15 msec longer (no effect on accuracy) when the flanker color (color diff) or both the flanker color and shape differed (two-feature diff) from the target probe ($ps < .01$). Fourth, in the two-feature judgment, the flanker caused more errors (no effect on RT) when its shape was different (shape diff) and its color was the same as the target probe ($p < .01$). Although RTs were not slower in the two-feature judgment when the flanker shape was different (shape diff), the high error rate is consistent with a speed–accuracy tradeoff interpretation. Thus, when the flanker had a different color and/or different shape from the target probe, the flanker interfered with the two-feature judgment. Taken together, these results demonstrate that the response mapping of flanker features along the relevant target dimensions influenced "absent" responses.

Multiple-feature costs. Consistent with a predictions, Figure 8 shows that "absent" RTs and error rates for the two-feature judgment increased as the number and discriminability of target features mapped to the "present" response increased. A two-way repeated measures ANOVA (target features present [3] × flanker [5]) was conducted on "absent" response RTs and accuracy for the two-feature judgment. There was a main effect of target features present for RT [$F(2,30) = 127.63, p < .001$] and accuracy [$F(2,30) = 33.88, p < .001$]. "Absent" RTs were slowest and least accurate when the most discriminable feature (i.e., color) was present and the least discriminable feature (i.e., shape) was absent [for RT, planned $F(1,15) = 85.71$; for accuracy, $F(1,15) = 22.54$; $ps < .001$]. "Absent" RTs and accuracy were intermediate when the least discriminable feature (i.e., shape) was present and the most discriminable feature (i.e., color) was absent [for RT, planned $F(1,15) = 254.12$; for accuracy, $F(1,15) = 45.91$; $ps < .001$]. Finally, RTs were fastest and most accurate when none of the features (i.e., color and shape) were mapped to the "present" response [for RT, planned $F(1,15) = 24.67$; for accuracy, $F(1,15) = 30.15$; $ps < .001$].

In addition, RTs and/or errors increased when a target probe feature(s) was mapped to the "absent" response and the flanker feature(s) along the same dimension was mapped to the "present" response. There was a main effect of flanker for RT [$F(4,60) = 10.69, p < .0001$] and accuracy [$F(4,60) = 3.15, p < .05$], and a target feature(s) present × flanker interaction for RT [$F(8,120) = 2.73, p < .01$] and accuracy [$F(8,120) = 2.60, p = .01$]. RTs and errors increased as the discriminability of the target features (mapped to the "present" response) contained in the flankers increased [color diff vs. shape diff; planned $F(1,15) = 12.40, p < .01$]. As shown in Figure 8, this latter effect was influenced by which of the target probe features were mapped to the "absent" response.

Summary. The results were consistent with the predictions. First, multiple-feature benefits and costs were found for feature judgments based only on color and shape. These findings indicate that the benefits and costs found in Experiments 1 and 2 were not dependent on the inclusion of a target feature that had low response accuracy (e.g., size). Second, there was no evidence indicating that the less discriminable feature (i.e., shape) was weighted less than the more discriminable feature (i.e., color) in the two-feature judgments. When the flanker shape was inconsistent with the target shape, "present" response RT was equally inflated in the two-feature and shape-alone judgments. Third, flanker interference was based on whether a flanker feature(s) was task relevant and whether this feature(s) was incompatible with a target feature(s) contained in the probe. This finding suggests that the irrelevant flanker features did not interfere with target feature discrimination. Finally, "absent" responses for the two-feature judgments were influenced by the discriminability of the target feature present in the flanker. Correct "absent" RTs were longer when the more discriminable target feature (i.e., color) was present in the flanker, relative to the less discriminable target feature (i.e., shape).

This latter finding suggests that the more discriminable target feature contained in the flanker interfered with the response decision earlier or began to prime its associated response (i.e., "present" response) before the less discriminable target feature. Note, however, that the two-feature "present" responses were not affected by the *discriminability* of the target features absent in the flanker (see two-feature judgments in Figure 7A). These findings suggest that the subjects were more sensitive to flanker features that were consistent with the target feature judgment (i.e., flanker features that were consistent with a "present" response, rather than an "absent" response). Furthermore, these findings again suggest that response or decision priming may be responsible for multiple-feature benefits and costs.

Another possibility, however, is that the multiple-feature benefits (and costs) found in Experiments 1–3 might have been due to contingencies inherent in our experimental design. For example, one possible explanation for multiple-feature benefits is that the more discriminable target features in our stimulus sets were correlated with the "present" response in the multiple-feature judgments. In Experiments 1–3, the appearance of the relevant, most discriminable feature (e.g., the color red) predicted a "present" response more often than an "absent" response in the arrays where multiple features were targets. For example, if the target features were *large red S*, then the probe letters containing the most discriminable feature (*red*) would predict a "present" response seven out of nine times (Experiment 1) and five out of eight times (Experiment 2). Also, the target features *red H* in Experiment 3 had probe letters containing *red* four out of six times. In contrast, the most discriminable feature (*red*) would equally predict a "present" or "absent" response when the target feature was only *large* (Experiments 1 and 2) or *H* (Experiment 3).

These probabilities are inherent in the stimuli sets used when equating the probability of "present" and "absent" responses. Multiple-feature benefits, however, cannot be completely due to correlated feature biases, because we found benefits to occur in the first block of trials in Experiment 1 (see Table 2), even though the subjects received only 16 practice trials beforehand.

Another possible explanation for multiple-feature benefits concerns the expected frequency of each target feature. The expected frequency of each target feature across the one-, two-, and three-feature judgments was not held constant in Experiments 1–3. For example, in Experiment 1, the expected frequency of the target feature on a one-feature judgment trial was .50, because half of the trials contained a target feature. On a two-feature trial, the expected frequency of each target feature was above .50, because a target feature appeared in all but two target-absent displays. On a three-feature trial, the expected frequency of each target feature was well above .50, because all but one of the target-absent displays contained at least one target feature. The expected frequency of each target feature also increased for the multiple-feature judgments in Experiments 2 and 3. Perhaps multiple-feature benefits are based on two things: the discriminability of the target feature, and the expected frequency of a target feature. If identification time decreases as the expected frequency of the target feature increases, multiple-feature benefits may be due to this contingency.[3]

EXPERIMENT 4

To ensure that the multiple-feature benefits found in Experiments 1–3 were not due to correlated feature biases or to the expected target frequency contingencies described above, Experiment 4 was conducted. Experiment 4 was similar to Experiment 3, with the exception that each possible letter stimulus (*red H*, *green H*, *red K*, *green K*) appeared equally often across each of the one-feature and two-feature judgments. Thus, for the two-feature judgments, stimuli requiring a "present" response appeared only one fourth of the time, and stimuli requiring an "absent" response appeared three fourths of the time. It was predicted that if correlated feature biases or expected target frequency contingencies were responsible for the multiple-feature benefits found previously, these benefits should disappear when these biases and contingencies are eliminated.

Method

Subjects. Nine male and 7 female undergraduates from Washington State University participated for optional research credit in a psychology course. All reported having normal color vision, and all had normal acuity assessed by a Snellen chart.

Apparatus, Stimuli, and Procedure. The experiment was identical to Experiment 3, with the following exceptions. Each probe stimulus appeared equally often across each of the one-feature and two-feature judgments. Thus, the color feature and the shape feature predicted a "present" response half of the time. However, three fourths of the two-feature judgment trials required an "absent" response, and only one fourth of these trials required a "present" response. The subjects completed 12 blocks of 40 trials in each of four sessions. Session 1 was practice and was not included in the data analyses.

Results and Discussion

In general, the results were similar to those found in Experiment 3 (see Figure 9 and Table 6 for RTs and errors, respectively). A repeated measures ANOVA (session [3] × response [2] × feature judgment [3] × Flanker [5]) was conducted on mean correct RTs and accuracy.[4] The significant main effects and interactions are presented in Table 7.

Only results related to multiple-feature benefits are discussed. Figure 10 shows the RT and errors for "present" and "absent" responses for each of the feature judgments, collapsed over flanker condition.

As shown in Figure 10, "present" and "absent" response RTs and accuracy varied across the different feature judgments. "Present" responses were fastest for the color-alone judgment [planned $F(1,15) = 60.54$, $p < .001$]. In addition, unlike in Experiment 3, there was no significant RT difference between the two-feature and shape-alone judgments for "present" responses ($p = .16$); however, the two-feature judgment was more accurate (by 4%) than the shape-alone judgment [planned $F(1,15) = 17.10$, $p < .001$]. "Present" responses for the two-feature judgment were as accurate as those for the color-alone judgment (planned $F < 1$). That is, although there was no difference in "present" RTs for the shape-alone and two-feature judgments, error rates were significantly higher for the shape-alone judgment. Thus, it appears that the RT for the shape judgment was lowered by a speed–accuracy tradeoff, given the high error rate.

Further support for this speed–accuracy tradeoff was found when examining error RTs. Mean error RTs were 438, 492, and 486 msec, for color, shape, and two-feature judgments, respectively. Error RTs were approximately 20 msec faster than correct RTs; however, error RTs and correct RTs showed the same pattern across feature judgments. Faster RTs for errors indicate that errors were mainly due to fast guesses, and it appears that these fast guesses occurred significantly more often for the shape-alone judgment.

These findings indicate that multiple-feature benefits based on accuracy were found for the two-feature judgment, relative to the shape-alone judgment. Also, a possible speed–accuracy tradeoff for the shape judgment might have been responsible for the reduced benefits found for RT.

The "absent" response data were similar to those found in Experiment 3. "Absent" responses were fastest and most accurate for the color-alone judgment [for RT, planned $F(1,15) = 70.81, p < .001$; for accuracy, $F(1,15) = 12.57$,

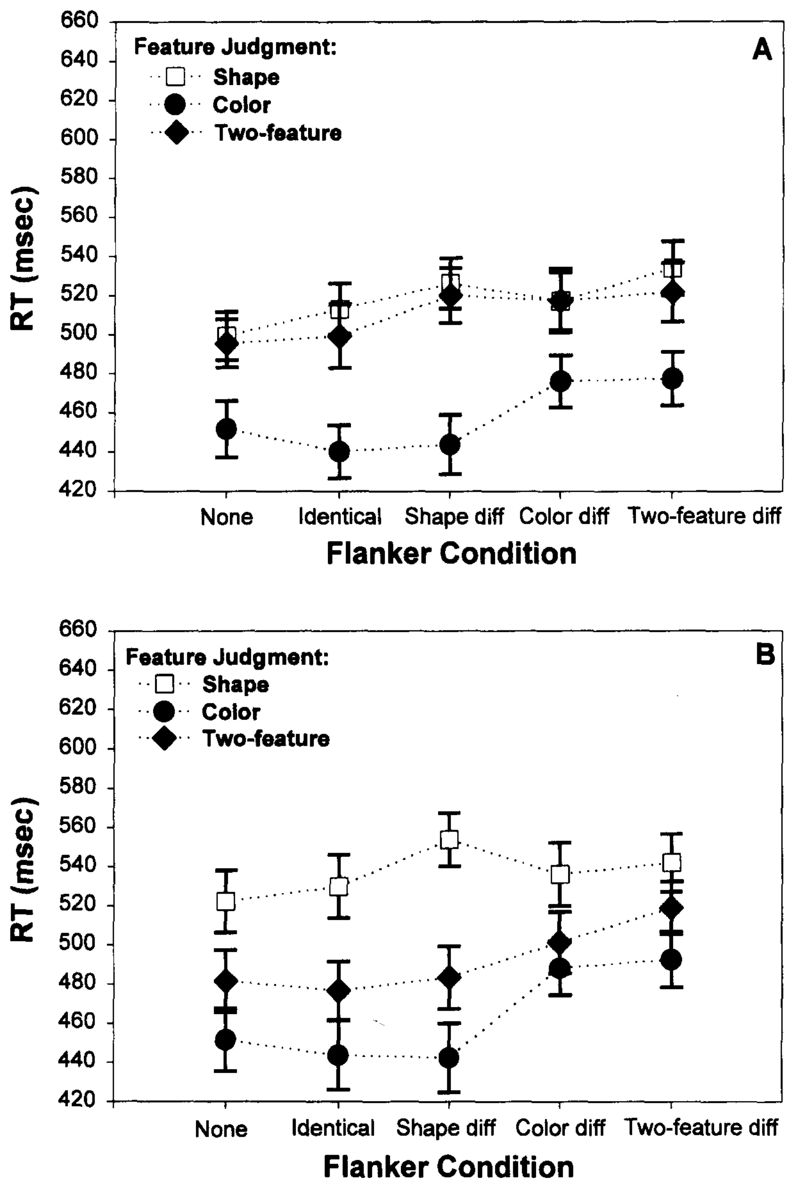

Figure 9. RTs for "present" responses (panel A) and "absent" responses (panel B) for each of the feature judgments across flanker conditions in Experiment 4. The levels of flanker conditions were as follows: none = no flanker; identical = flanker identical to probe; shape diff = flanker shape different from probe; color diff = flanker color different from probe; two-feature diff = both flanker features different from probe.

$p < .01$], intermediate for the two-feature judgment, and slowest and least accurate for the shape-alone judgment [for RT, planned $F(1,15) = 66.94, p < .001$; for accuracy, $F(1,15) = 5.31, p < .05$].

However, unlike Experiment 3, "absent" responses were faster than "present" responses for the two-feature judgment (response $\times$ feature judgment). This was most likely due to the higher probability of "absent" responses (75%), relative to "present" responses (25%), for the two-feature judgment. Perhaps the criterion for an "absent" response for the two-feature judgment was lower than the criterion for a "present" response.

In sum, multiple-feature benefits (in terms of accuracy) were found for "present" responses when each possible letter stimulus (*red H, green H, red K, green K*) appeared equally often across each of the one-feature and two-feature judgments. Thus, multiple-feature benefits found in Experiments 1–3 were not completely due to correlated feature biases or contingencies based on expected target frequency. In addition, benefits were found for the

Table 6
Percent Errors for Each Feature Judgment Across Flanker Condition for "Present" and "Absent" Responses in Experiment 4

Feature Judgment	Flanker Condition				
	none	identical	shape diff	color diff	two-feature diff
"Present" Response					
shape	7.21	6.69	13.38	9.09	14.09
color	4.31	4.65	5.48	10.00	8.64
two-feature	4.81	5.08	7.75	6.35	8.08
"Absent" Response					
shape	5.67	3.64	8.48	3.60	5.71
color	2.52	1.52	1.75	4.44	4.37
two-feature	5.00	3.69	4.54	3.37	4.58

Table 7
Correct Response Time and Accuracy ANOVA Tables for Significant Effects in Experiment 4

Factor	Significance	MS_e
Response Time		
session	$F(2,30) = 9.12, p < .001$	6,572
feature	$F(2,30) = 92.97, p < .001$	5,798
flanker	$F(4,60) = 62.22, p < .001$	795
response × feature	$F(2,30) = 23.73, p < .001$	2,026
feature × flanker	$F(8,120) = 17.66, p < .001$	626
response × feature × flanker	$F(8,120) = 3.15, p < .01$	645
Accuracy		
response	$F(1,15) = 14.27, p < .01$	.0286
feature	$F(2,30) = 23.72, p < .001$	.0064
flanker	$F(2,30) = 10.20, p < .001$	.0047
response × session	$F(2,30) = 3.69, p < .05$	.0037
response × flanker	$F(4,60) = 6.37, p < .001$	.0044
session × flanker	$F(8,120) = 2.00, p = .05$	.0039
feature × flanker	$F(8,120) = 4.04, p < .001$	.0056

Note—feature = feature judgment.

two-feature judgment even though "present" responses were less correlated with the correct response (only 25% of the trials). There was, however, a reduction in RT benefits, relative to what was found in Experiments 1–3. Thus, it is possible that correlated feature biases and contingencies based on expected frequencies contribute to multiple-feature benefits.

GENERAL DISCUSSION

The results of these experiments demonstrate that judging the presence of multiple features, in which one feature is relatively difficult to discriminate and one or more features are relatively easy to discriminate, can be faster and more accurate than judging the presence of the less discriminable feature alone (multiple-feature benefits). In addition, judging the absence of one or more multiple target features led to slower and less accurate "absent" responses as the number and discriminability of target features present in the object increased (multiple-feature costs). Multiple-feature benefits and costs were found when several different target feature combinations were discriminated or a subset of target feature combinations was discriminated. In addition, benefits and costs were found when the target object appeared alone or among irrelevant objects and when the target appeared in a fixed or random spatial location.

Factors Not Responsible for Benefits and Costs

Several explanations of multiple-feature benefits and costs were ruled out in this study. First, Experiment 2 showed that benefits and costs were not due to differential presentation frequency of the target features or combination of target features. Benefits and costs were found when each subject judged the presence and absence of all possible target feature combinations across trials. However, benefits were not as strong as those found in Experiments 1 and 3. Perhaps this was because target features were consistently mapped in the multiple-feature judgments in Experiments 1 and 3 but not in Experiment 2. This finding suggests that reducing the feature-to-response mapping ratio may lead to more robust multiple-feature benefits.

Second, Experiment 3 showed that benefits and costs were not due to the subjects' strategically weighting their decisions on the more discriminable target features. The least discriminable feature (i.e., shape) was weighted equally when judging the presence of this feature alone or in conjunction with a more discriminable feature (i.e., color). Specifically, "present" response RTs were equally inflated in the two-feature color and shape judgments and in the shape-alone judgments when the flanker's least discriminable feature (i.e., shape) was inconsistent with the correct "present" response. Error RTs also indicated that "present" responses were not based on fast guesses in the two-feature judgments. Thus, it is unlikely that benefits were based on guesses leading to more false alarms.

Third, Experiment 4 showed that multiple-feature benefits were not completely due to correlated feature biases or to contingencies based on differential target feature expectancies across the feature judgments. When each feature within the target object equally predicted a "present" or "absent" response in single- and multiple-feature judgments, multiple-feature benefits were observed. However, benefits were based on accuracy only. The lack of multiple-feature benefits based on RT might have been a result of the fast RTs and high error rates found for the less discriminable target feature (i.e., shape judgment), which was likely due to a speed–accuracy tradeoff.

In addition, the reduction in RT benefits in Experiment 4 might have been due to a decrease in the correlation between the "present" response and the correct response in the multiple-feature judgments. "Present" responses occurred on only 25% of the multiple-feature judgment trials, whereas they occurred on 50% of the single-feature judgment trials. This reduction in "present" response frequency for multiple-feature judgments might have led to an "absent" response bias, resulting in slower "present" responses. While this explanation and

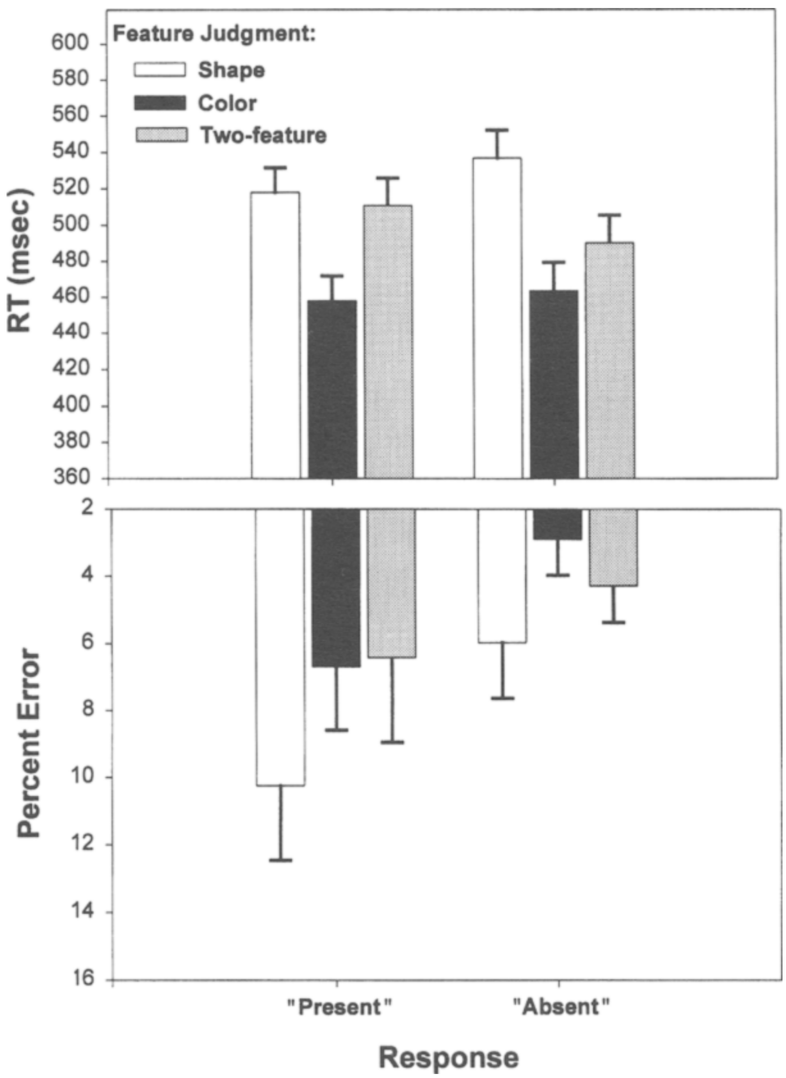

Figure 10. RTs and percent errors for "present" and "absent" responses for each of the feature judgments collapsed over flanker conditions in Experiment 4.

a possible speed–accuracy interpretation might account for reduced benefits based on RT, a possible contingency explanation cannot be completely ruled out. This is because multiple-feature benefits were larger in Experiments 1 and 3, in which these biases and contingencies were the greatest.

Simple Serial and Parallel Models

The results of the present study bear on the validity of simple serial and parallel models of feature processing: That is, such models have difficulty accounting for multiple-feature benefits. However, a simple parallel model may be consistent with multiple-feature benefits if benefits are based on decision or response priming by each target feature, and this priming is combined to reach a decision or response criterion (e.g., Miller, 1982a, 1982b). This model is referred to as the *asynchronous priming* (AP) model. In addition, the number of possible stimuli mapped to the "present" response (e.g., Nickerson, 1973) or the number of memory set items compared against the target object may also contribute to multiple-feature benefits (e.g., Ratcliff, 1978). Before discussing these possibilities, the flanker results in Experiment 3, which provide insights into multiple-feature benefits, will be discussed.

Flanker Interference and Insights Into Benefits and Costs

Flanker interference in Experiment 3 was based on whether a flanker feature(s) was task relevant and whether the feature was incompatible with a target feature contained in the probe. For example, when shape was the target feature and only the flanker color was different from the probe, the flanker color did not interfere with the probe shape discrimination. This finding suggests that the irrelevant flanker features did not interfere (or interfered very little) with target feature discrimination within the probe. This is consistent with past research that shows that irrelevant items are not analyzed in as much detail as relevant items (e.g., Rabbit, 1967).

In addition, when the flanker features matched the target features but were incompatible with the correct "absent" response, the amount of interference depended on target feature discriminability. For example, when the target color was present in the flanker, it interfered more with "absent" responses, relative to when the target shape was present in the flanker. This finding suggests that interference occurred earlier when the target feature contained in the flanker was more discriminable. It is possible that the more discriminable target feature primed its associated response earlier than the less discriminable target feature. Discrimination RT benefits have been shown to increase as the priming lead time increases for the correct response (Flowers & Wilcox, 1982). Also, this assumption is consistent with the findings of Grice, Boroughs, and Canham (1984), who showed that discrimination of target stimuli affects the rate of growth of associative strength for the correct response.

Furthermore, evidence consistent with response priming is found when evaluating the multiple-feature costs for "absent" responses in Experiments 1–4. Multiple-feature costs were based on the discriminability of the target features that were mapped to the "present" response. Specifically, increasing the discriminability of target features mapped to the "present" response led to greater increases in RTs and errors for "absent" responses. For example, when the target features color and shape were mapped to the "present" response, "absent" responses were longer and less accurate, relative to when only the target feature shape was mapped to the "present" response.[5]

Possible Models That Can Account for Multiple-Feature Benefits

An AP model (similar to the asynchronous discrete model discussed by Miller, 1982a),[6] a response mapping model (see, e.g., Hick, 1952; Hyman, 1953), and a memory comparison (template) model (see, e.g., Ratcliff, 1978) may account for multiple-feature benefits. The AP model assumes that all features within an object are processed in a parallel, independent fashion, and each target feature primes its task-relevant response (e.g., "present" or "absent"). Target features that are relatively easy to discriminate (e.g., color) are assumed to prime their responses on average before features that are more difficult to discriminate (e.g., size; see also Grice et al., 1984; Grice, Canham, & Schafer, 1982). Furthermore, it is assumed that priming from the different features are combined to meet the response criterion (Fournier & C. W. Eriksen, 1990; Miller, 1982a, 1982b). This may lead to multiple-feature benefits when all of the target features are mapped to the same response and may lead to multiple-feature costs when target features are not mapped to the same response. Thus, the speed and accuracy of responses depend on the discriminability of the target features mapped to the same or different response and may also depend on the strength of the target feature–response mapping.

In contrast, the response mapping model predicts multiple-feature benefits based on the number of possible stimuli mapped to the "present" response. In our study, the number of possible stimuli (letter probes) that matched the target feature description decreased as the number of target features increased. For example, when the features *large red S* were targets, only one stimulus alternative (*large red S*) matched this description. When the feature *large* was a target, four different stimulus alternatives (*large red S*, *large green S*, *large red C*, or *large green C*) matched this description. Decreasing the number of possible stimulus alternatives mapped to a single response is known to decrease response latency and errors (see Nickerson, 1973, for a review). This factor, along with the assumption that more discriminable target features prime responses earlier than the less discriminable features (see Kahneman, 1973), may account for multiple-feature benefits.

Memory comparison, or template, models (see Farell, 1984; Ratcliff, 1978; Sternberg, 1969; see also Prinz & Scheerer-Neumann, 1974) also assume that RTs are influenced by the set of stimulus alternatives mapped to the positive response (e.g., "present" response). The positive stimulus alternatives are each represented by a template in memory, and a stimulus must be compared with these templates before a positive or negative response can be executed. Thus, reducing the number of stimulus alternatives (templates) mapped to the positive response will reduce response RTs. A template model, such as the memory retrieval model proposed by Ratcliff (1978), can account for multiple-feature benefits and costs.

This model assumes that probe and memory set item (template) features are compared in a parallel, independent, and continuous (random-walk) fashion. In addition, probe–template comparison time is dependent on (1) the discriminability among the memory set items and the distractors, (2) the order of the feature comparisons and the distribution of matching and nonmatching features within that order (Ratcliff, 1978, p. 63), and (3) the decision boundaries for "present" and "absent" responses (which vary according to the information required for a decision). Thus, multiple-feature benefits and costs may be accounted for by assuming that the order of probe–template feature comparison is biased toward comparing the most discriminable target features with the template first, followed by the less discriminable target features, and then followed by any nontarget features (order of comparison which may also be based on discriminability). The important assumption is that object features are compared asynchronously on the basis of feature discriminability, and evidence indicating a match or mismatch is combined to meet a decision criterion. Multiple-feature benefits will occur if all of the target features are present, and costs will occur when some target features are present and some are absent.

These three models can also account for the weaker benefits found in Experiments 2 and 4 by assuming response priming is reduced or the "present" response criterion is increased (e.g., Nickerson, 1973; Rabbit, 1967) when increasing the number of targets mapped to a specific response (Experiment 2), when increasing the possible responses linked to a single stimulus (Experiment 2), or when reducing the probability of a particular response (Experiment 4). The AP model predicts that these weaker benefits are based on a reduction in response priming. In contrast, the memory retrieval model (e.g., Ratcliff, 1978) predicts that these weaker benefits are based on a higher "present" response criterion. Furthermore, the response mapping model can account for weaker benefits based on reductions in response priming and/or an increase in the "present" response criterion. Note, however, that the AP model, but not the response mapping model or the memory retrieval model, has difficulty accounting for benefits based on accuracy alone in Experiment 4. The AP model could account for the findings in Experiment 4 if the lack of RT benefits are due to a speed–accuracy tradeoff.

Conclusions

In sum, our results imply that the final output of processing (response) can be faster when judging the presence of multiple features, as opposed to a single feature. These findings are not consistent with simple serial and parallel models of feature processing. However, models that assume that responses or decisions are asynchronously primed by each target feature (based on feature discriminability) and are combined to meet a response or decision criterion may account for multiple-feature benefits (e.g., the AP and memory retrieval models). Also, models that assume that both the number of stimuli mapped to a particular response and the discriminability of target features influence response or decision times can account for multiple-feature benefits. Finally, other explanations based on contingencies (e.g., expected target frequencies) may also contribute to multiple-feature benefits, since benefits were stronger when these contingencies were present. A challenge for future research will be to determine the robustness of multiple-feature benefits and the processes underlying this phenomenon.

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NOTES

1. Multiple-feature benefits and costs were also found when stimulus sets (instead of messages) were presented, and the subjects determined whether the probe stimulus was a member of the stimulus set (similar to a Sternberg paradigm; e.g., Sternberg, 1969).

2. When the factor of session was included, all effects were identical to those found for the three-way ANOVA. However, the main effect of session approached significance [$F(2,30) = 2.77$, $p = .078$], and there was a significant session × response × flanker interaction for RTs. Flankers that had a different shape from the target showed decreased RT interference across sessions for "absent" responses, but they were no different across sessions for "present" responses. In addition, there was a session × response × feature judgment interaction for accuracy [$F(4,48) = 2.70$, $p < .05$], indicating that "present" responses for shape judgments were less accurate for Session 4, whereas "absent" response accuracy for shape judgments did not change across sessions.

3. Toby Mordkoff, personal communication, December 1996.

4. The main effect of session for correct RTs and a response × session interaction for accuracy indicate that RTs were faster and "present" response accuracy was better during the last session.

5. The only exception to this example was found in Experiment 2, which showed no difference in "present" response RT for the color-alone and shape-alone judgments. Also, there was no significant difference in multiple-feature costs for "absent" responses when color alone or shape alone was mapped to the "present" response. These findings suggests that these two features were not different in discriminability. However, multiple-feature benefits and costs based on discriminability were found in Experiment 2 (see Figures 4, 5, and 6).

6. Whether features are processed discretely and activate their associated responses (e.g., Miller, 1982a; Sanders, 1981) or are processed in a continuous fashion and activate their associated responses before feature evaluation is complete (e.g., Coles et al., 1985; Coles, Scheffers, & Fournier, 1995; C. W. Eriksen & Schultz, 1979; Gratton, Coles, Sirevaag, C. W. Eriksen, & Donchin, 1988; Grice et al., 1984; Osman, Bashore, Coles, & Donchin, 1992; Smid, Mulder, & Mulder, 1990) will not be debated.

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