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Illusory Conjunctions Are an Illusion: The Effects of Target–Nontarget Similarity on Conjunction and Feature Errors

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The results of previous studies on visual perception suggest that conjunction errors partly derive from imperfect binding of correctly perceived features. However, the paradigms used in these studies do not generally allow one to discriminate between errors of feature binding and errors of target–nontarget confusion. In Experiments 1–4, an altered paradigm was used enabling discrimination between errors of feature binding and errors of target–nontarget confusion. The results showed that conjunction errors between color and identity do not derive from imperfect binding. In Experiments 5 and 6, a typical mainstream paradigm was used. The results indicated that, in such a paradigm, data patterns suggesting the existence of illusory conjunctions are likely to be due to errors of target–nontarget confusion instead of imperfect feature binding.

When several different objects are simultaneously presented, observers, under some conditions, may report erroneous combinations of concurrently presented features. Treisman and Schmidt (1982) were the first to systematically investigate this phenomenon. Basically, they had participants perform two simultaneous tasks. In a primary task, participants were to report two black digits, one placed at each end of a row of three colored letters. The aim of this task was to prevent attention from being focused on the secondary task. In the secondary task, participants were to report the color and shape of any letters they had seen. The major finding was that, under conditions of limited exposure duration, participants frequently reported incorrect combinations of colors and forms. Because the number of these so-called conjunction errors largely exceeded the number of feature errors (i.e., reports of features that were not present in the display), Treisman and Schmidt (1982) inferred that a substantial part of the number of conjunction errors reflected "illusory conjunctions," which are percepts in which visual features are correctly identified but incorrectly combined. In line with feature integration theory (Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Sato, 1990), it was concluded that in preattentive vision, a feature is free floating and may be combined with any other feature that has been identified.

Although conjunction errors have been found in numerous studies, many authors have reported results that are inconsistent with the idea of completely free-floating features in preattentive vision (Cohen & Ivry, 1989; Ivry & Prinzmetal, 1991; Keele, Cohen, Ivry, Liotti, & Yee, 1988; Prinzmetal & Keysar, 1989; Prinzmetal, Presti, & Posner, 1986; Tsal, Meiran, & Lavie, 1994). For example, several studies have demonstrated that the number of conjunction errors strongly depends on whether display items are close together or far apart. Thus, the number of conjunction errors increases as the distance between elements decreases.[1] Because the variance in conjunction errors could not be explained on the basis of feature errors alone, it was suggested that some of the conjunction errors indeed reflected illusory conjunctions. However, the hypothesis of complete absence of location information in preattentive vision was discarded. Instead, preattentive feature registration is assumed to include at least some coarse location information. This may, under conditions of high element proximity, lead to illusory conjunctions (Cohen & Ivry, 1989).

Unfortunately, findings in previous studies on illusory conjunctions were generally interpreted on the basis of relatively simple probabilistic considerations. Comparing the number of conjunction errors with the number of feature errors is not necessarily a good reflection of the occurrence of illusory conjunctions (Ashby, Prinzmetal, Ivry, & Maddox, 1996; Navon & Ehrlich, 1995; Tsal, 1989). In a standard experiment on conjunction and feature errors, participants are briefly presented with two or more elements randomly selected from a limited set of stimuli. Typically, participants have the task of reporting the identity and color of a target element. In such a task, it is very probable that, for example, they happen to guess the correct identity of the

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[1] The reason for the lack of distance effects in the original study of Treisman and Schmidt (1982) might have been that the study was not explicitly designed to evaluate distance effects (see Prinzmetal & Keysar, 1989, p. 175).

target element and the color of the nontarget element. Depending on the probability with which individual features are correctly perceived, it may even be that guessing chances on conjunction errors are larger than guessing chances on feature errors. If this is true, it may well be that conjunction errors result exclusively from guessing instead of imperfect location information in preattentive vision.

Recently, Ashby et al. (1996) developed a formal method to discriminate the probability of correctly perceiving features from the probability of correctly conjoining them. The method, which bears on techniques developed by Batchelder and Riefer (1990; Riefer & Batchelder, 1988), allows one to compare various theoretical approaches regarding feature binding while taking into account differential probabilities of feature identification. Basically, the method involves the construction of a multinomial model explicitly describing all possible theoretical states and how they lead to specific response types given a certain theory of feature binding.

To compare the alternative theoretical notions of feature binding, Ashby et al. (1996) constructed several multinomial models assuming either imperfect feature binding or perfect feature binding. Imperfect binding models are models allowing correctly identified features to be incorrectly combined, whereas perfect binding models do not allow for this possibility. Two experiments were performed in which participants were simultaneously presented with a colored target letter (*T* or *X*) and a colored nontarget letter (*C* or *S*). Letter colors were sampled randomly and without replacement from a set of three colors (red, yellow, and blue). Target and nontarget were presented in peripheral vision at four different distances from each other. Participants were asked to either report the identity and color of the target letter (Experiment 1) or report the identity and color of the target letter as well as the nontarget color (Experiment 2). As a means of determining whether performance was better described by models assuming imperfect binding or models assuming perfect binding, the alternative multinomial models were separately fit to the data of the individual participants. Basically, the models assuming imperfect binding provided the best fit to the data. Furthermore, estimates of the probability of correct binding decreased with decreasing interitem distance. The best fit to the data was provided by the imperfect binding model assuming location uncertainty, which is in accordance with previous studies on feature binding (Chastain, 1982; Cohen & Ivry, 1989; Gallant & Garner, 1988; Keele et al., 1988; Wolford & Shum, 1980).

According to a location uncertainty model (Ashby et al., 1996), the perceived location of a feature varies from trial to trial and is bivariately normally distributed with a variance, σ^2, and a mean equaling the actual location. An illusory conjunction is assumed to occur when the perceived location of the nontarget color is closer to the perceived location of the target identity than is the perceived location of the target color. Because the variance, σ^2, of the distribution of perceived locations is assumed to increase with eccentricity and decrease with attention, the chances of this occurring are predicted to become higher with increasing eccentricity of stimulus presentation and decreasing attention. Furthermore, the chances of illusory conjunctions are predicted to increase with decreasing distance between target and nontarget (Ashby et al., 1996).

The formal approach of Ashby et al. (1996) represents a substantial improvement over past methods of data analysis in feature binding experiments. Basically, it allows for a precise comparison of alternative theories of feature binding by formalizing the alternative theoretical notions. Furthermore, it permits the estimation of underlying psychological parameters from overt behavior, which may significantly contribute to an understanding of psychological phenomena underlying object perception. Finally, it points to the important fact that the probability of perceiving individual features is crucial in determining behavioral data patterns. Despite this, the study of Ashby et al. (1996) is similar to previous studies on illusory conjunctions based on experiments that may suffer from one major shortcoming: The paradigm used does not allow discrimination of possible errors of feature binding from errors of target–nontarget confusion.

To date, every study on interdimensional illusory conjunctions (i.e., illusory conjunctions between two values of two different dimensions, such as color and shape) has used a paradigm in which conjunction errors may occur not only as a result of guessing or imperfect feature binding but also as a result of target–nontarget confusion. Typically, on each trial, a target letter and a nontarget letter are simultaneously presented. In such a situation, a target element may be misperceived as a nontarget element or the other way around, independently of the identity of the other element presented. Possible misperceptions of a nontarget as a target or a target as a nontarget may lead to data patterns that support illusory conjunctions, whereas actually feature binding might have been perfect.

For example, suppose participants have to report the identity and color of one target letter drawn from a set consisting of *T* and *X* that is concurrently presented with a nontarget letter drawn from a nontarget set consisting of *C* and *S*. If participants are presented with a red *X* and a yellow *S*, it is imaginable that they falsely perceive the *S* as being an *X* independently of the target letter actually presented. On such trials, participants are likely to make a color conjunction error, which is not due to imperfect binding but to the misperception of the nontarget letter. Various studies on the perception of letters in peripheral vision suggest that the probability of misperceiving one specific letter as another letter (i.e., confusing two letters) is, to a large extent, determined by the dissimilarity in their global features (e.g., height-to-width quotient) as opposed to their local features (Bouma, 1971; Jacobs, Nazir, & Heller, 1989). Thus, the use of letter stimuli that can be discriminated from each other on the basis of highly dissimilar local features (e.g., horizontalness vs. verticalness) certainly does not guarantee that they cannot be confused. In addition, the probability that two letters are confused has been found to increase with increasing retinal eccentricity and decreasing interitem distance (Appelman & Mayzner, 1982; Bouma, 1970; Krumhansl & Thomas, 1977).

Appelman and Mayzner (1982), for instance, reviewed several studies on the probability of correctly identifying a letter under adverse viewing conditions (e.g., large spatial density). One recurring finding was that the proportions of letter confusions increase when interitem distance decreases. In a similar vein, Bouma (1971) found that proportions of letter confusions dramatically grow with retinal eccentricity. Thus, findings of increasing differences between the number of conjunction and feature errors with decreasing interitem distance might also be attributed to increasing probabilities of misperception caused by confusion instead of decreasing probabilities of correct feature binding.

The aim of the present study was to investigate whether or not conjunction errors partly derive from imperfect feature binding while controlling for possible errors of target–nontarget confusion. The paradigm used deviated from the traditionally used paradigm in experiments on illusory conjunctions. Basically, only two values were used for the selection-relevant dimension, along with two values for the response-relevant dimension. As a means of obtaining sufficient data, the identities of the selection-relevant dimension and the response-relevant dimension were switched over conditions. This paradigm allowed independent estimation of the probability of discriminating the target from the nontarget (which includes the probability that the target and nontarget are not confused) and the probability of correct binding using the method proposed by Ashby et al. (1996).

In the first three experiments, stimuli were matched with respect to their luminance values and numbers of pixels to minimize possible feature-dependent processing. In Experiment 4, letter stimuli were used to enable generalization to previous studies. In Experiment 5, the stimuli used in the first four experiments were applied in a typical mainstream paradigm. Finally, Experiment 6 investigated how target–nontarget similarity affects the probability of correct feature binding in a typical mainstream paradigm.

Experiment 1

The aim of Experiment 1 was to test whether or not conjunction errors partly reflect illusory conjunctions. Participants were instructed to perform two simultaneous tasks. In the primary task, they had to vocally indicate the identity of a centrally presented digit. The purpose of the primary task was to direct attention away from the secondary task and to have participants fixate on the center of the screen. Concurrently with digit presentation, one target element and one nontarget element were presented at adjacent positions on an imaginary circle centered around central fixation (for a similar paradigm, see Cohen & Ivry, 1989). The secondary task was to indicate the value of one dimension of the target element by means of a button press. The major manipulation involved variation of the identity of the selection-relevant and response-relevant dimensions in the secondary task. There were four conditions varying in both the selection-relevant dimension and the response-relevant dimension. In two conditions the response-relevant dimension was color, whereas in the other two conditions the response-relevant dimension was orientation.

In the orientation–color condition (OC condition), the selection-relevant dimension was orientation and the response-relevant dimension was color. In each trial, one vertical and one horizontal rectangle were simultaneously presented in such a way that one rectangle's position was always above the position of the other rectangle. The color of each rectangle could be either yellow or whitish blue and was independently determined for each stimulus. Furthermore, it was equally probable that the position of each rectangle was above or below the other rectangle. The task of participants was to indicate the color of the vertical rectangle (see the upper-left panel of Figure 1).

In the location–color condition (LC condition), the selection-relevant dimension was relative location and the response-relevant dimension was color. Stimuli were the same as in the OC condition. The selection-relevant dimension was different: Participants had to indicate the color of the upper rectangle, which, as in the OC condition, could be either yellow or blue (see the upper-right panel of Figure 1).

In the color–orientation condition (CO condition), the selection-relevant dimension was color and the response-relevant dimension was orientation. In each trial, one whitish blue and one yellow rectangle were simultaneously presented, with one rectangle always positioned above the other one. The orientation of each rectangle could be either horizontal or vertical and was independently determined for each stimulus. In addition, it was equally probable that the position of each rectangle was above or below the other rectangle. The task of participants was to indicate the

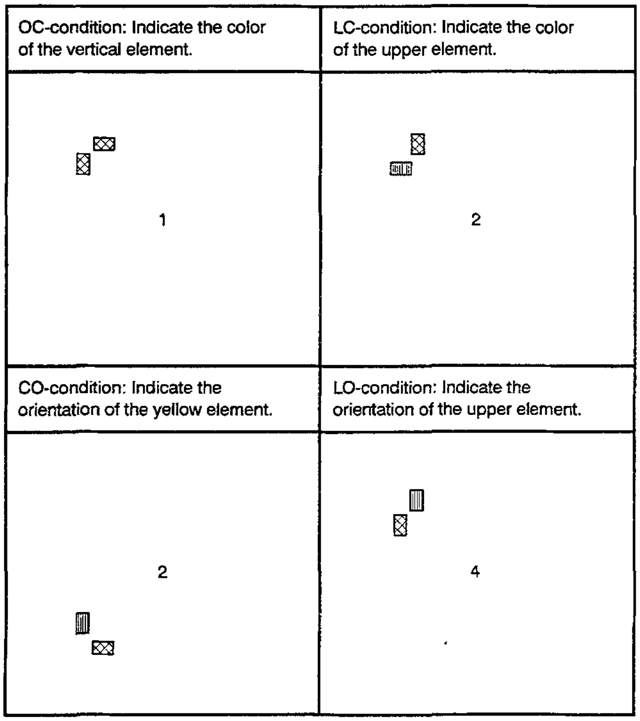

Figure 1. Four sample displays from Experiment 1. Checked rectangles correspond to yellow rectangles. Vertically striped rectangles correspond to blue rectangles (measures and distances are not in proportion to the actual situation). OC = orientation–color; LC = location–color; CO = color–orientation; LO = location–orientation.

orientation of the yellow rectangle (see the lower-left panel of Figure 1).

In the location–orientation condition (LO condition), the selection-relevant dimension was relative location and the response-relevant dimension was orientation. Stimuli were the same as in the CO condition. Participants had to indicate the orientation of the upper rectangle, which, as in the CO condition, could be either horizontal or vertical (see the lower-right panel of Figure 1).

Figure 2 depicts all possible stimulus combinations with the corresponding response categories separately for each condition. Within each condition, every stimulus combination was presented equally often.

Basically, the tasks in the OC and CO conditions most closely matched the task in a typical illusory conjunction experiment. Participants were required to select a target element on the basis of a nonspatial dimension and to report the value of another nonspatial dimension. The LC and LO conditions were different from a typical experiment on illusory conjunctions in that the selection-relevant dimension was a spatial one. As mentioned earlier, in contrast to paradigms in previous studies on illusory conjunctions, the present paradigm enabled independent estimation of the probability of correctly discriminating the target from the nontarget and the probability of correct feature binding using the method proposed by Ashby et al. (1996).

The Model

Following Ashby et al. (1996), formal multinomial tree structures (Batchelder & Riefer, 1986, 1990; Riefer & Batchelder, 1988) were developed, enabling direct comparison of the various theoretical approaches to feature binding. In each condition of Experiment 1, participants were presented with two elements. Each element had one of two possible colors and one of two possible orientations. The value of the response-relevant dimension was independently determined for each element. In contrast, for the selection-

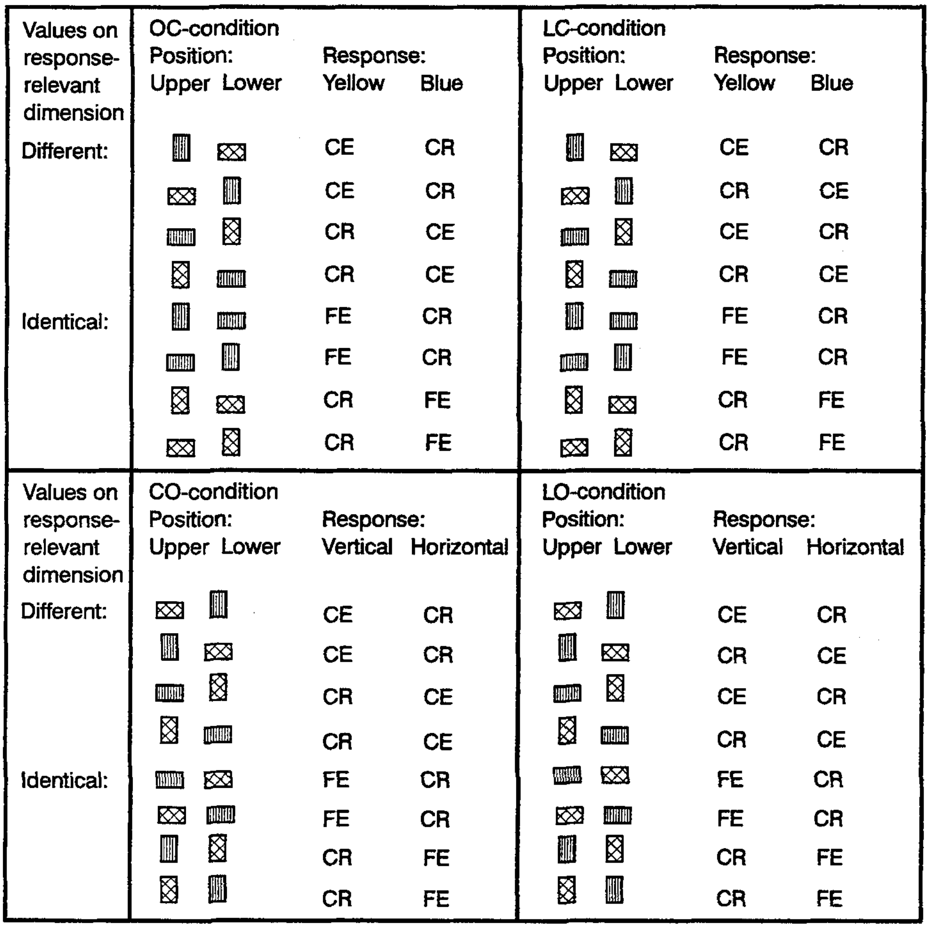

Figure 2. All possible stimulus combinations with the corresponding response categories for every condition, arranged in relation to whether the values of the response-relevant dimension are different (upper parts of the panels) or identical (lower parts of the panels). Checked rectangles correspond to yellow rectangles. Vertically striped rectangles correspond to blue rectangles. CE = conjunction error; CR = correct response; FE = feature error; OC = orientation–color; LC = location–color; CO = color–orientation; LO = location–orientation.

relevant dimension, the target had always one value and the nontarget the other value.

If the simultaneous perception of different features occurs in a statistically independent fashion (Link, 1982; Lord & Novick, 1968), the probability of a certain outcome should be predictable on the basis of the tree diagrams illustrated in Figure 3. Figure 3 delineates four tree diagrams depicting all possible theoretical states and how they lead to specific response types within one condition separate for trials in which the response-relevant dimension has two different values (different trials) as opposed to two identical values (identical trials). On the basis of these tree diagrams, the expected proportion for each response category is given by the sum of the paths corresponding to that category. For example, the expected proportion of feature errors (*FE*) in the identical trials of the LC condition (LCi) is given by

$$p(FE)_{LCi} = trc \times (1 - nrc) \times (1 - \alpha) \times 1/2 + (1 - trc) \times nrc \times \alpha\, 1/2 + (1 - trc) \times (1 - nrc) \times 1/2,$$

in which *trc* corresponds to the probability of perceiving the target color, *nrc* corresponds to the probability of perceiving the nontarget color, and α corresponds to the probability of correct feature binding. The expected proportion of feature errors in different trials of the LC condition is zero. In general, feature errors can occur only in identical trials, whereas conjunction errors can occur only in different trials (see Figure 3). Consequently, expected proportions corresponding to the alternative response categories are separately expressed for different and identical trials. Generally, the diagrams in Figure 3 indicate that the expected proportion of a response in a certain response category depends on the probability of discriminating the target from the nontarget, the probability of perceiving the target value of the response-relevant dimension, the probability of perceiving the nontarget value of the response-relevant dimension, and the probability of correct binding.

Similar to the binomial models of Ashby et al. (1996), the present model allows maximum-likelihood estimation of free parameters on the basis of observed individual proportions of responses in the various response categories. Different from the models of Ashby et al. (1996) is that these estimates are based on separate conditions and trials. Furthermore, the present model includes a parameter corresponding to the probability of discriminating the target from the nontarget.

Because α is a free parameter, the model in Figure 3 depicts all possible states and their expected outcomes assuming imperfect feature binding. To compare an imperfect binding account with a perfect binding notion, the imperfect binding model depicted in Figure 3 can be easily adjusted to account for perfect binding by fixing the value of the parameter α to 1. In the following, models with a variable α are generally referred to as imperfect binding models, whereas models with α fixed at a value of 1 are referred to as perfect binding models.

If conjunction errors do not derive from illusory conjunctions, α is expected to be 1, and the perfect binding model will provide the best fit to the data. Furthermore, at a performance level, perfect binding should result in no difference between the number of conjunction and feature errors in the LC and LO conditions. This becomes apparent when comparing the expected proportion of conjunction errors with the expected proportion of feature errors in, for instance, the LC condition (see upper-right panel of Figure 3). If α equals 1, all $(1 - \alpha)$ branches fall off. Because the number of different trials equals the number of identical trials, the expected number of conjunction errors is equal to the expected number of feature errors. In the OC and CO conditions, an α of 1 is not a sufficient condition for the expected proportion of conjunction errors to be equal to the expected proportion of feature errors. For example, in the OC condition, the expected proportion of conjunction errors will be equal to the expected proportion of feature errors only if α equals 1 and the probability of correctly discriminating the target from the nontarget, *so*, equals 1 (see upper-left panel of Figure 3).

If conjunction errors partly derive from incorrectly combining correctly perceived features, α should be lower than 1, and the imperfect binding model should provide the best fit to the data. An imperfect binding model predicts that the total number of conjunction errors will always be higher than the total number of feature errors (see Figure 3).[2]

Experiment 1 was not a direct test of the location uncertainty model, because neither interitem distance nor retinal eccentricity or attention was manipulated. However, its major aim was to investigate whether or not a feature is completely free floating, as originally suggested by Treisman and Schmidt (1982).

Method

Participants. Eight participants took part in the present experiment. All had normal or corrected-to-normal vision.

Task and stimuli. Stimuli were presented on a Low Radiation MPR-II monitor controlled by a 486DX2 PC. Participants performed in two simultaneous tasks. The primary task involved the report of a centrally presented digit (1, 2, 3, or 4; subtending 0.51° of visual angle in width and 0.64° of visual angle in height at an observation distance of 0.45 m). Oral reports were recorded on a tape recorder (Sony). In the secondary task, participants were to select one of two elements on the basis of the selection-relevant dimension and to indicate the value of the response-relevant dimension by means of a button press.

In each trial, two elements were presented in adjacent positions on an imaginary circle (radius of 4.83° of visual angle) centered around central fixation. The center-to-center distance between two

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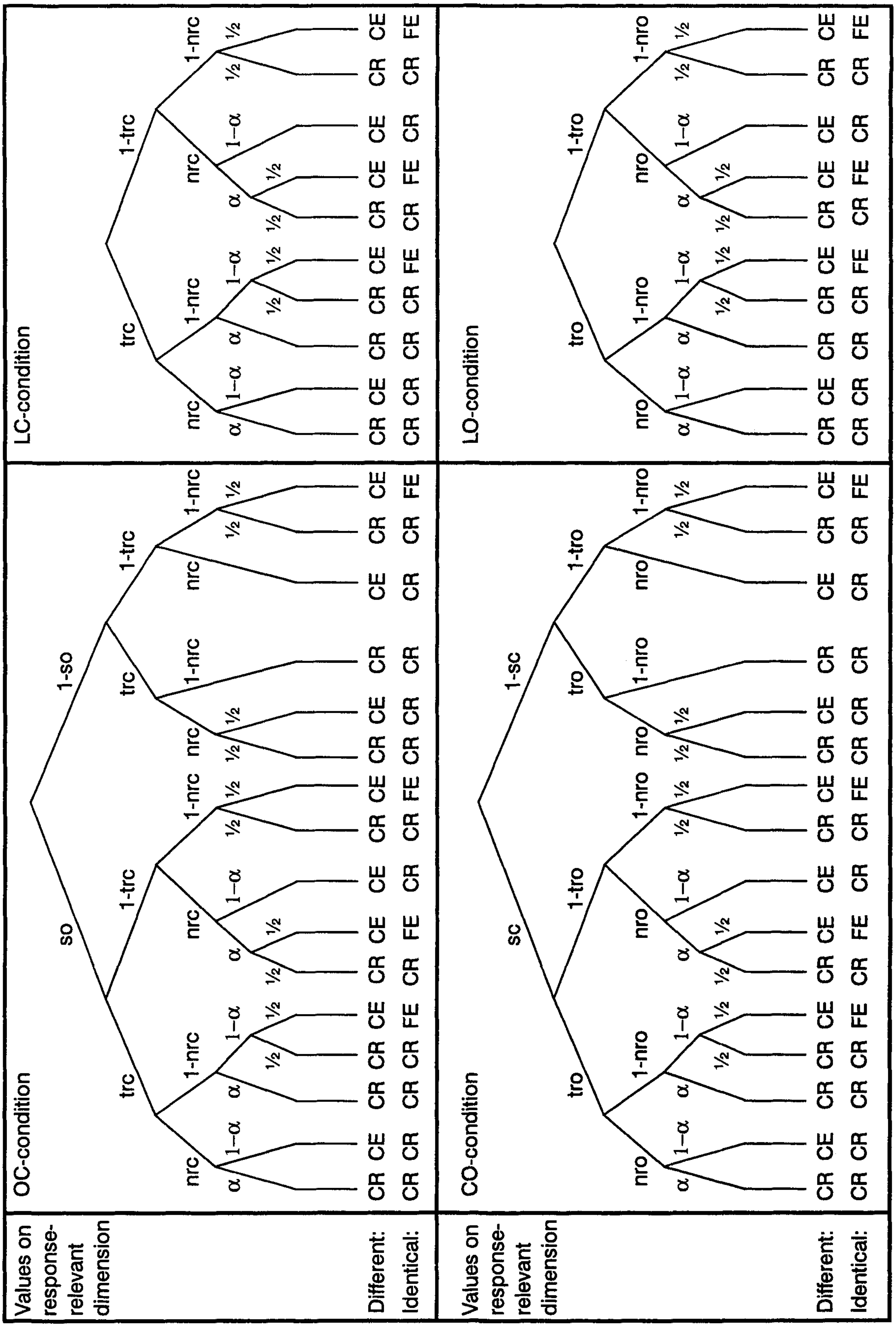
[2] If the probability of perceiving the nontarget value of the response-relevant dimension is zero, both a perfect binding model and an imperfect binding model predict the number of conjunction errors to be equal to the number of feature errors. However, considering the fact that the nontarget value of the response-relevant dimension is defined on the basis of a primitive feature, it is highly unlikely that this is ever the case (Treisman & Gelade, 1980). This possibility is therefore not considered to be a serious alternative.


Values on response-relevant dimension
Different:
Identical:
OC-condition
so
1-so
trc
1-trc
nrc
1-nrc
α
1−α
½
CR CE CR CR CE CR CE CE CR CE CR CE CR CE CR CE
CR CR CR CR FE CR FE CR CR FE CR CR CR CR CR FE
LC-condition
trc
1-trc
nrc
1-nrc
α
1−α
½
CR CE CR CR CE CR CE CE CR CE
CR CR CR CR FE CR FE CR CR FE
Values on response-relevant dimension
Different:
Identical:
CO-condition
sc
1-sc
tro
1-tro
nro
1-nro
α
1−α
½
CR CE CR CR CE CR CE CE CR CE CR CE CR CE CR CE
CR CR CR CR FE CR FE CR CR FE CR CR CR CR CR FE
LO-condition
tro
1-tro
nro
1-nro
α
1−α
½
CR CE CR CR CE CR CE CE CR CE
CR CR CR CR FE CR FE CR CR FE

elements of a pair was 0.84° of visual angle. Pairs were randomly presented in a direction 45°, 135°, 225°, or 315° of arc on the imaginary circle. Each direction occurred equally often. Elements were whitish blue (CIE x, y chromaticity coordinates of .214, .305) or yellow (x, y = .397, .527) rectangles (0.28° × 0.45° of visual angle). Both color and orientation values were determined, on the basis of a pilot study, to achieve independent feature processing of one dimension from the other. Three participants took part in the pilot study. There were two conditions. In one condition, participants indicated the color of an element while orientation was varied, whereas, in the other condition, participants indicated the orientation of an element while color was varied. The values of color and orientation were chosen such that reaction time concerning the value of one dimension was independent of the value of the other dimension.

Elements had equal luminances (approximately 70.0 cd/m^2), as determined by a flicker fusion test (Ives, 1912), and were projected at a gray background (19.1 cd/m^2). The exposure duration of the digit and the rectangles was about 50 ms (i.e., 3 raster cycles). After 50 ms, masks consisting of horizontal and vertical stripes (subtending 0.50° of visual angle in width and 0.55° of visual angle in height, with a luminance of 110.8 cd/m^2) replaced the stimuli until a response was given.

Design. A within-subjects design was used. Participants performed in four different conditions presented in four separate blocks. Each block consisted of a practice and an experimental part. The sequence of block presentation was determined according to a Latin square. Type of trial was varied within blocks. That is, within each block, the proportion of different trials was equal to the proportion of identical trials. Dependent variables were numbers of correct responses, numbers of conjunction errors, and numbers of feature errors.

Procedure. Each trial started with the presentation of a tone (5000 Hz, 200 ms) immediately followed by the presentation of a fixation point in the middle of the screen. After 1 s, the fixation point was replaced by one of four possible digits concurrently with two elements adjacently positioned on an imaginary circle. After approximately 50 ms, the digit and the two peripheral elements were masked until a response was given on the secondary task. The next trial started 2 s after the response of the participant.

Each participant performed in four blocks corresponding to the four conditions during one session of about 3 hr. Each block consisted of a practice and an experimental part. The practice part consisted of 256 trials. Display presentation times were approximately 83 ms (i.e., 5 raster cycles) during the first 128 practice trials and approximately 66 ms (i.e., 4 raster cycles) during the second 128 practice trials. The subsequent experimental part consisted of 256 trials in which the time of display presentation was about 50 ms (i.e., 3 raster cycles). Participants were free to take a break during and between blocks.

Figure 3 (opposite). Four tree diagrams corresponding to the four conditions. Each tree diagram depicts the outcome on every trial as a function of the product of the probability of discriminating the target from the nontarget on the basis of the selection-relevant dimension (i.e., *so*, corresponding to the probability of discriminating the target from the nontarget on the basis of orientation, and *sc*, corresponding to the probability of discriminating the target from the nontarget on the basis of color), the probability of perceiving the target value of the response-relevant dimension (i.e., *trc*, corresponding to the probability of perceiving the target color, and *tro*, corresponding to the probability of perceiving the target orientation), the probability of perceiving the nontarget value of the response-relevant dimension (i.e., *nrc*, corresponding to the probability of perceiving the nontarget color, and *nro*, corresponding to the probability of perceiving the nontarget orientation), and α, the probability of correct binding. CR = correct response; CE = conjunction error; FE = feature error; OC = orientation–color; LC = location–color; CO = color–orientation; LO = location–orientation.

Results

The primary task was included to ensure that participants attended to and fixated on the center of the display during task performance. Because digit report was verbal, errors on the primary task were extremely rare for all participants (2.1% of trials or less). Analyses of performance in the secondary task included all trials.

Response categories. Table 1 depicts the mean proportions of correct responses, the mean proportions of conjunction errors, and the mean proportions of feature errors as a function of condition. Average proportions of correct responses showed that performance was better in the LC condition than in the LO condition, $F(1, 7) = 29.73$, $p < .001$, indicating that observers were better in discriminating yellow from blue than in discriminating vertical from horizontal. Furthermore, the proportion of correct responses was higher in the LC condition than in the OC condition, $F(1, 7) = 18.77$, $p < .003$, and lower in the LO condition than in the CO condition, $F(1, 7) = 6.02$, $p < .044$. Within the LC condition, performance was independent of the orientation of the target, $F(1, 7) = 0.10$. In the LO condition, performance was independent of the color of the target, $F(1, 7) = 0.18$.

A multivariate analysis of variance (MANOVA)[3] on the mean individual differences between the proportions of conjunction and feature errors showed a significant effect of condition, $F(3, 5) = 7.79$, $p < .025$. There was a significant difference between the number of conjunction and feature errors in the OC condition, $F(1, 7) = 15.50$, $p < .006$, whereas such a difference was not present in the LC condition, $F(1, 7) = 4.08$, $p > .050$; the CO condition, $F(1, 7) = 5.46$, $p > .050$; and the LO condition, $F(1, 7) = 0.67$.

Theoretical analysis. As a means of investigating whether the present data are better described by a model assuming imperfect feature binding or a model assuming perfect feature binding, both models were separately fit to the data of each participant. For both models, maximum-likelihood estimates of free parameters were obtained via an iterative search procedure (Hu & Batchelder, 1994). The maximum-likelihood estimates are those parameter values

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[3] Because the experiment was based on repeated measurements, MANOVAs were performed on the data when the independent variable had more than two levels. Furthermore, Wilks's lambda was used, and the reported F values represent approximate values (Stevens, 1992).

Table 1
Mean Proportions of Correct Responses, Conjunction Errors, and Feature Errors as a Function of Condition: Experiment 1

Category	Condition OC	LC	CO	LO
Correct response	.84	.97	.80	.69
Conjunction error	.15	.02	.12	.16
Feature error	.02	.01	.08	.15

Note. Columns may not sum to 1.00 as a result of rounding errors. OC = orientation–color; LC = location–color; CO = color–orientation; LO = location–orientation.

that minimize $-2lnL$, which is given by

$$-2\sum_{i}^{n} f_i \ln P_i$$

where f_i is the observed response frequency in cell i of the data matrix and P_i is the probability of this type of response as predicted by the model. Because there were four conditions (OC, LC, CO, and LO), two types of trials (different and identical), and two possible responses per type of trial, there were 16 cells in the data matrix for each participant ($4 \times 2 \times 2$) and 8 degrees of freedom.

Both the imperfect and the perfect binding models were separately fit, either assuming all parameters to be free or constraining the values corresponding to the nonreported features to equal the values of the corresponding reported features, that is, assuming $nrc = trc$ (in the following denoted as c, the probability of perceiving the color) and $nro = tro$ (in the following denoted as o, the probability of perceiving the orientation). Partial G^2 values were calculated to compare the goodness of fit of the constrained models with that of the unconstrained models. Partial G^2 is given by

$$2\sum_{i}^{n} f_i \ln \frac{P_{i(UM)}}{P_{i(CM)}},$$

in which f_i is the observed response frequency in cell i of the data matrix, $P_{i(UM)}$ is the probability of this type of response as predicted by the unconstrained model, and $P_{i(CM)}$ is the probability of this type of response as predicted by the constrained model. Partial G^2 follows a chi-square distribution with v degrees of freedom equaling the difference in the number of free parameters between the unconstrained and constrained models.

For each participant, constraining the values of the nonreported features to those of the reported features did not affect the goodness of fit, as indicated by partial G^2 ($df = 2$). Furthermore, there was no difference in the probability of correct binding, α, when the fits of the constrained models were compared with those of the unconstrained models. Therefore, in the following, the reported model fits are those performed with models in which $nrc = trc$ (denoted as c) and $nro = tro$ (denoted as o) unless reported differently (see also Ashby et al., 1996, p. 183). As a means of comparing the perfect binding model with the imperfect binding model, partial G^2 was calculated for each participant (the constrained model corresponded to the perfect binding model, and the unconstrained model corresponded to the imperfect binding model).

Table 2 presents the individual maximum-likelihood estimates of α, sc, c, so, and o separately for the perfect and imperfect binding models and the corresponding partial G^2 values ($df = 1$). For every participant, the additional free parameter of the imperfect binding model did not provide a significant improvement in fit over the more parsi-

Table 2
Individual Parameter Estimates From Best-Fitting Models and Partial G^2 Values: Experiment 1

Model and parameter	Participant MK	FV	CD	ML	JB	JJ	JO	JD
Imperfect binding model								
α	.99	1.00	.98	1.00	.97	1.00	.99	1.00
sc	.60	1.00	1.00	.51	.88	1.00	1.00	.89
c	.84	.99	.95	.91	.98	.95	.89	.94
so	.02	.99	.55	.66	.04	.39	.64	.70
o	.28	.82	.38	.63	.31	.50	.33	.79
Perfect binding model								
sc	.60	1.00	1.00	.51	.87	1.00	1.00	.88
c	.83	.98	.93	.91	.96	.95	.88	.94
so	.01	.98	.53	.66	.01	.39	.63	.69
o	.28	.82	.37	.63	.30	.50	.33	.78
Partial G^2	0.02	0.03	1.02	0.00	2.00	0.00	0.10	0.05

Note. α = probability of correct binding; *sc* = probability of discriminating the target from the nontarget on the basis of color; *c* = probability of perceiving the color; *so* = probability of discriminating the target from the nontarget on the basis of orientation; *o* = probability of perceiving the orientation.

monious perfect binding model.[4] Basically, the absolute fits of the perfect binding model were extremely good. On average, the perfect binding model accounted for about 97% of the variance in the data.

Additional fits were performed in which α was fixed at a value of .95, yielding an imperfect binding model with the same number of free parameters as the perfect binding model. A direct comparison of $-2lnL$ showed that the perfect binding model still provided a better fit to the data than the imperfect binding model for 7 out of the 8 participants. An analysis of variance (ANOVA) on the parameter estimates of the perfect binding model showed that *sc* and *c* were larger than *so* and *o*, $F(1, 7) = 19.43$, $p < .003$.

Discussion

The major result of Experiment 1 is that there was no difference between the number of conjunction and feature errors in the LC condition, the CO condition, or the LO condition. The only significant difference was found in the OC condition. If some of the conjunction errors were due to participants erroneously combining correctly perceived features, the number of conjunction errors should have exceeded the number of feature errors in all conditions. Illusory conjunctions are supposed to be independent of both the identity of the selection-relevant and the response-relevant dimensions. Because the present results are incompatible with this prediction, it seems that conjunction errors are not the result of illusory conjunctions. The theoretical analysis completely converged with the behavioral findings. For every participant, the additional free parameter of the imperfect binding model did not provide a significant improvement in fit over the perfect binding model. Even an imperfect binding model assuming α to be fixed at a value of .95 did not yield better fits to the data than those of the perfect binding model.

It is striking that the difference between the number of conjunction and feature errors did not reach significance in the CO condition, whereas it did in the OC condition. As already outlined in the introduction, if the probability of correctly discriminating the target from the nontarget equals 1, a perfect binding model predicts the difference between the number of conjunction and feature errors to be zero. Inspection of the parameter estimates showed that *sc* was 1 for 4 of the 8 participants, whereas *so* was smaller than 1 for every participant. Because color was the selection-relevant dimension in the CO condition and orientation was the selection-relevant dimension in the OC condition, the present behavioral outcome is exactly the one predicted by the perfect binding model.

One curious finding in Experiment 1 is that the number of correct responses in the CO condition exceeded the number of correct responses in the LO condition. Apparently, participants were better able to discriminate vertical from horizontal when they had to select the yellow element (CO condition) than when they had to select the upper element (LO condition). It is very unlikely that this difference was caused by a higher visibility of yellow as opposed to blue, because great care was taken to equalize the colors used in terms of visibility (see Method section). Furthermore, performance in the LO condition did not depend on whether the target element was yellow or blue. Consequently, it seems implausible that these results were due to unequal visibility. A more likely explanation would be that, in the CO condition, the advance color information provided a possibility for selective processing to occur. In the CO condition the target was always yellow, whereas in the LO condition the target was either yellow or blue. As a result, in the CO condition, the preattentive system could have been selectively tuned to the processing of yellow, with the result that the orientation of the target element was more often correctly discriminated than in the LO condition. In the LO condition, such a strategy was not possible because the target could be either yellow or blue (Cave & Wolfe, 1990; Wolfe, 1994; Wolfe, Cave, & Franzel, 1989). If this occurs, the assumption of feature-sampling independence might be violated.

As a means of investigating what the consequence would be of a possible feature-sampling dependency, alternative models were constructed assuming a dependency in the CO condition between the probability of discriminating the target from the nontarget on the basis of color, *sc*, and the probability of perceiving the target orientation, *tro* (see Figure 3). That is, separate estimates were obtained of *tro* conditioned on whether or not the target was discriminated from the nontarget. The alternative models were separately fit to the data of the individual participants. The major finding was that the introduction of a dependency did not affect the α estimates at all. The perfect binding model always provided the best fit to the data. Thus, even if a possible dependency was available, it seems highly unlikely that this affected α. Obviously, if α in truth would have been smaller than 1, then, irrespective of condition, the number of conjunction errors should always have been larger than the number of feature errors.

Despite the evidence provided by Experiment 1 in favor of a perfect binding model, it would be premature to dismiss all illusory conjunction accounts. Interpretation of the results of Experiment 1 is bounded by at least two serious limitations.

First, neither retinal eccentricity nor interitem distance was varied in Experiment 1. A location uncertainty model assumes that the occurrence of illusory conjunctions is conditional on overlapping distributions of perceived locations. As discussed earlier, amount of overlap is proportionally related to retinal eccentricity and inversely proportionally related to interitem distance. Without varying these variables, it is difficult to dismiss a location uncertainty model, because it always remains theoretically possible that retinal eccentricity was too small or interitem distance too large for illusory conjunctions to occur. A comparison of the values of interitem distance and retinal eccentricity in the

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[4] Fitting the initial unconstrained models to the data yielded the same results. That is, for every participant, the additional free parameter of the imperfect binding model did not provide a significant improvement in fit over the perfect binding model.

present experiment with those used by Ashby et al. (1996) shows no substantial deviation, however. Nevertheless, it seems appropriate to manipulate these variables to provide a more accurate test.

A second difficulty concerns the results. An advocate of an illusory conjunction account could argue that, although nonsignificant in all conditions, there was a tendency for more conjunction errors to occur than feature errors.

As a means of further testing the perfect binding model against the imperfect binding model, a second experiment was executed. This experiment was similar to Experiment 1 except that, in the secondary task, elements could be presented at two different retinal eccentricities. In addition, elements were presented at two different distances from each other.

Experiment 2

Method

Participants. Eight participants took part in Experiment 2. All had normal or corrected-to-normal vision.

Task and stimuli. The tasks and stimuli were the same as in Experiment 1, except that the elements in the secondary task were adjacently positioned on one of two imaginary circles (radii of 2.42° of visual angle and 7.22° of visual angle, with an observation distance of 0.45 m) centered around central fixation. Furthermore, interitem distance between elements was varied. The center-to-center distance between two elements of a pair was either 0.55° (near) or 1.64° (far).

Design. A within-subjects design was used. Participants performed in four different conditions (i.e., OC condition, LC condition, CO condition, and LO condition) presented in four blocks. Each block consisted of a practice and an experimental part. The sequence of block presentation was determined according to a Latin square. Eccentricity, interitem distance, and type of trial were varied within blocks. Dependent variables were number of correct responses, number of conjunction errors, and number of feature errors.

Procedure. The procedure was the same as in Experiment 1. Each participant performed in four blocks corresponding to the four conditions during two sessions (on separate days) of about 3 hr each. Each block consisted of a practice and an experimental part. The practice part consisted of 256 trials. Display presentation times were about 83 ms (i.e., 5 raster cycles) during the first 128 practice trials and approximately 66 ms (i.e., 4 raster cycles) during the second 128 practice trials. After practice, participants proceeded with the experimental part, which consisted of 512 trials (128 trials per combination of eccentricity and interitem distance). The exposure duration during the experimental part was about 50 ms (i.e., 3 raster cycles). Participants were free to take a break during and between blocks.

Results

Errors in the primary task were rare for all participants (2.4% of trials or less). Analyses of performance in the secondary task therefore included all trials.

Response categories. Table 3 shows the mean proportions of correct responses, the mean proportions of conjunction errors, and the mean proportions of feature errors separately for each level of condition, eccentricity, and interitem distance. Average proportions of correct responses in the LC and LO conditions show that observers were generally better able to discriminate yellow from blue than to discriminate vertical from horizontal, $F(1, 7) = 24.13$, $p < .002$. Furthermore, in the LC condition, the proportion of correct responses was higher than in the OC condition, $F(1, 7) = 24.25$, $p < .002$. There was no difference in the proportion of correct responses between the LO condition and the CO condition, $F(1, 7) = 0.38$. Over all conditions, the number of correct responses decreased with eccentricity, $F(1, 7) = 129.50$, $p < .001$, and, at 7.22°, increased with interitem distance, $F(1, 7) = 24.47$, $p < .002$.

Table 3

Mean Proportions of Correct Responses (CR), Conjunction Errors (CE), and Feature Errors (FE) as a Function of Eccentricity, Interitem Distance, and Condition: Experiment 2

	OC		LC		CO		LO	
Category	Near	Far	Near	Far	Near	Far	Near	Far
	Eccentricity 2.42°							
CR	.89	.89	.97	.96	.86	.87	.84	.85
CE	.10	.10	.01	.02	.08	.07	.10	.08
FE	.02	.01	.02	.02	.06	.06	.06	.07
	Eccentricity 7.22°							
CR	.76	.83	.92	.94	.67	.77	.69	.73
CE	.20	.14	.04	.02	.18	.11	.16	.14
FE	.04	.03	.04	.05	.15	.12	.15	.13

Note. Columns may not sum to 1.00 as a result of rounding errors. OC = orientation–color; LC = location–color; CO = color–orientation; LO = location–orientation.

A MANOVA on the mean individual differences between the proportions of conjunction and feature errors showed a significant effect of condition, $F(3, 5) = 20.88$, $p < .003$. In the OC condition, there were more conjunction errors than feature errors, $F(1, 7) = 62.24$, $p < .001$, whereas this was not the case in the LC condition, $F(1, 7) = 4.59$, $p > .050$; the CO condition, $F(1, 7) = 1.98$, $p > .050$; and the LO condition, $F(1, 7) = 2.61$, $p > .050$. Furthermore, in the OC condition, the difference between the proportions of conjunction and feature errors became larger with eccentricity, $F(1, 7) = 7.89$, $p < .027$, and, at 7.22°, if interitem distance decreased, $F(1, 7) = 10.48$, $p < .014$.

Theoretical analysis. Both models were separately fit to the data of each participant to further investigate whether the data of Experiment 2 are better described by a model assuming imperfect feature binding or perfect feature binding. As in Experiment 1, there were four conditions (OC, LC, CO, and LO), two types of trials (different and identical), and two possible responses per type of trial. In addition, there were two different eccentricities and two different interitem distances, resulting in 64 cells in the data matrix for each participant ($4 \times 2 \times 2 \times 2 \times 2$) and 32 degrees of freedom.

The imperfect binding model and the perfect binding model were separately fit to the data of each participant, yielding distinct parameter estimates for each combination

Table 4
Individual Parameter Estimates From Best-Fitting Models and Partial G^2 Values: Experiment 2

Model and eccentricity–interitem distance	Parameter	Participant							
		JD	HS	JK	HV	AZ	TL	MV	FV
Imperfect binding model									
2.42° near	α	.99	1.00	1.00	.93	.99	1.00	.99	1.00
	sc	1.00	.66	1.00	.94	1.00	.70	.82	.99
	c	.96	.89	.95	.99	.98	.95	.89	.92
	so	1.00	.40	.89	.88	.71	.45	.49	.68
	o	.96	.59	.95	.79	.91	.62	.34	.64
2.42° far	α	1.00	1.00	1.00	1.00	.99	.98	.99	1.00
	sc	.97	.78	1.00	.83	.98	1.00	1.00	1.00
	c	.95	.89	.91	.96	.97	.98	.87	.95
	so	.92	.28	1.00	.73	.78	.49	.28	.70
	o	.97	.45	.96	.73	.88	.67	.45	.69
7.22° near	α	.99	.85	1.00	1.00	1.00	1.00	1.00	1.00
	sc	.68	.50	1.00	.63	1.00	.33	.13	.60
	c	.89	.66	.89	.71	.92	.78	.68	.91
	so	.26	.30	.66	.05	.34	.37	.36	.45
	o	.59	.29	.50	.41	.59	.25	.07	.34
7.22° far	α	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	sc	.89	.96	1.00	1.00	1.00	1.00	1.00	1.00
	c	.87	.68	.92	.91	.89	.82	.80	.95
	so	.71	.23	.77	.62	.76	.45	.43	.46
	o	.63	.34	.73	.39	.71	.28	.39	.52
Perfect binding model									
2.42° near	*sc*	.99	.66	1.00	.87	1.00	.70	.81	.99
	c	.95	.89	.95	.97	.97	.95	.88	.92
	so	1.00	.40	.89	.77	.70	.45	.48	.68
	o	.95	.59	.95	.72	.90	.62	.34	.64
2.42° far	*sc*	.97	.78	1.00	.83	.97	.98	1.00	1.00
	c	.95	.89	.91	.95	.97	.96	.87	.95
	so	.92	.28	1.00	.73	.77	.47	.27	.70
	o	.97	.45	.96	.73	.87	.66	.45	.69
7.22° near	*sc*	.67	.40	1.00	.63	1.00	.33	.13	.60
	c	.89	.59	.89	.71	.92	.78	.68	.91
	so	.25	.17	.66	.05	.34	.37	.36	.45
	o	.58	.26	.50	.41	.59	.25	.07	.34
7.22° far	*sc*	.89	.96	1.00	1.00	1.00	1.00	1.00	1.00
	c	.88	.68	.92	.91	.89	.82	.80	.95
	so	.71	.23	.77	.62	.76	.45	.43	.46
	o	.63	.34	.73	.39	.71	.28	.39	.52
Partial G^2		0.63	2.36	0.00	5.01	0.74	0.59	0.04	0.00

Note. α = probability of correct binding; *sc* = probability of discriminating the target from the nontarget on the basis of color; *c* = probability of perceiving the color; *so* = probability of discriminating the target from the nontarget on the basis of orientation; *o* = probability of perceiving the orientation.

of eccentricity and interitem distance. As in Experiment 1, for each participant, constraining the values of the nonreported features to those of the reported features—that is, $nrc = trc$ (denoted as c) and $nro = tro$ (denoted as o)—did not affect the goodness of fit, as evident from the partial G^2 value ($df = 8$). Furthermore, there was no difference in the probability of correct binding, α, when the constrained model fits were compared with the unconstrained model fits. Therefore, in the following, the reported model fits are those performed with models in which $nrc = trc$ (denoted as c) and $nro = tro$ (denoted as o) unless reported differently (see also Ashby et al., 1996, p. 183).

Table 4 shows the individual maximum-likelihood estimates separately for the perfect and imperfect binding models, along with the corresponding partial G^2 values ($df = 4$). For every participant, the additional free parameters of the imperfect binding model did not provide a significant improvement in fit over the perfect binding model.[5] As in Experiment 1, the absolute fits of the perfect binding model were very good. On average, the perfect binding model accounted for about 98% of the variance in the data.

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[5] Fitting the initial unconstrained models to the data yielded the same results. That is, for every participant, the additional free parameter of the imperfect binding model did not provide a significant improvement in fit over the perfect binding model.

Table 5
Individual Goodness-of-Fit Values (Akaike Information Criterion): Experiment 2

	Perfect binding model				Imperfect binding model				
Participant	Model A	Model B	Model C	Model D	Model A	Model B	Model C	Model D	Model E
JD	1,094.69	1,217.07	1,089.95	1,214.08	1,102.06	1,177.14	1,095.97	1,170.90	1,093.56
HS	2,061.52	2,092.59	2,052.72	2,087.22	2,067.17	2,081.42	2,056.09	2,077.06	2,052.10
JK	1,054.60	1,139.05	1,053.99	1,142.55	1,062.60	1,134.63	1,060.64	1,133.27	1,056.64
HV	1,605.67	1,667.95	1,609.38	1,671.95	1,608.65	1,670.42	1,614.50	1,667.56	1,611.21
AZ	1,172.73	1,206.58	1,168.23	1,205.69	1,179.99	1,211.75	1,175.24	1,208.33	1,172.02
TL	1,821.82	1,867.52	1,810.87	1,864.65	1,829.23	1,868.90	1,818.84	1,863.70	1,814.84
MV	2,078.80	2,085.00	2,083.98	2,092.70	2,086.76	2,092.99	2,091.80	2,099.25	2,087.93
FV	1,594.77	1,607.26	1,588.88	1,608.15	1,602.77	1,614.97	1,596.85	1,614.01	1,592.85

Note. Model A = model in which *sc, c, so,* and *o* are free over eccentricity and interitem distance (the original model); Model B = model in which *sc, c, so,* and *o* are fixed over eccentricity; Model C = model in which *sc, c, so,* and *o* are fixed over interitem distance; Model D = model in which *sc, c, so,* and *o* are fixed over eccentricity and interitem distance; Model E = model in which *sc, c, so,* and *o* are fixed over interitem distance and the perceived location of a feature is assumed to be bivariately normally distributed, with a mean equaling the actual location and with a variance, σ_1^2, at eccentricity 2.42° and a variance, σ_2^2, at eccentricity 7.22° (location uncertainty model). *sc* = probability of discriminating the target from the nontarget on the basis of color; *c* = probability of perceiving the color; *so* = probability of discriminating the target from the nontarget on the basis of orientation; *o* = probability of perceiving the orientation.

Because a location uncertainty model predicts α to increase as a function of eccentricity and to decrease as a function of interitem distance, an ANOVA was performed on the individual maximum-likelihood estimates of α. This analysis showed no effect at all: eccentricity, $F(1, 7) = 0.01$; interitem distance, $F(1, 7) = 1.91, p > .050$; and Eccentricity × Interitem Distance, $F(1, 7) = 0.33$.

An ANOVA on the parameter estimates of the perfect binding model showed that *sc* and *c* were larger than *so* and *o*, $F(1, 7) = 64.51, p < .001$. Furthermore, the values of all estimates decreased with increasing eccentricity, $F(1, 7) = 103.88$, $p < .001$, and with decreasing interitem distance, $F(1, 7) = 44.63, p < .001$. The effect of interitem distance was larger at an eccentricity of 7.22° than at an eccentricity of 2.42°, $F(1, 7) = 33.23, p < .001$.

As in Experiment 1, additional fits were performed with an imperfect binding model in which α was fixed at a value of .95. A direct comparison of $-2lnL$ showed that, for every participant, the perfect binding model provided a better fit to the data than the imperfect binding model.

As a means of placing more burden on the α parameters, further models were developed in which *sc, c, so,* and *o* were held fixed across eccentricity; *sc, c, so,* and *o* were held fixed across interitem distance; and *sc, c, so,* and *o* were held fixed across eccentricity and interitem distance. Finally, a location uncertainty model was formulated in which *sc, c, so,* and *o* were assumed to be constant over interitem distance and the perceived location of each feature was assumed to be bivariately normally distributed, with a mean equaling the actual location and with a variance, σ_1^2, at eccentricity 2.42° and a variance, σ_2^2, at eccentricity 7.22°. The present location uncertainty model is basically identical to the one of Ashby et al. (1996), except that it is suited to be applied in the current experiment.

All models were fit to the individual data. The Akaike information criterion (AIC) was used to compare the goodness of fit of the alternative models (Akaike, 1974; Ashby et al., 1996; Takane & Shibayama, 1992).[6] Table 5 depicts the individual goodness-of-fit values for the alternative models. For 7 of the 8 participants, a model assuming perfect binding provided the best fit to the data. For 1 participant (HS), the location uncertainty model provided the best fit. Basically, equalizing the values of *sc, c, so,* and *o* over eccentricity or interitem distance resulted in small α estimates in particular at an interitem distance of 0.55° and an eccentricity of 7.22°. Nevertheless, a comparison of the AIC values reveals that, in general, models assuming perfect binding provided a better fit to the data than models assuming imperfect binding.

Discussion

The results of Experiment 2 provide strong evidence for a perfect binding model assuming that conjunction errors do not derive from illusory conjunctions. Several outcomes substantiate this conclusion.

First, as in Experiment 1, the number of conjunction errors did not exceed the number of feature errors in the LC condition, CO condition, or LO condition, whereas it did in the OC condition. If some of the conjunction errors derived from participants incorrectly combining correctly perceived features, the number of conjunction errors should have exceeded the number of feature errors in all conditions.

Second, for every participant, the additional free parameters of the imperfect binding model did not provide any

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[6] The AIC statistic enables the comparison of models with different numbers of free parameters. The AIC used in the present experiments was defined by

$$-2\sum_i f_i \ln P_i + 2n$$

in which f_i is the observed response frequency in cell i in the data matrix, P_i is the probability of this type of response as predicted by the model, and n is the number of free parameters. The best model is the model with the smallest AIC value (Ashby et al., 1996).

significant improvement in fit over the more parsimonious perfect binding model. An imperfect binding model assuming α to be fixed at a value of .95 provided a worse fit to the data than the perfect binding model did. Furthermore, even when more burden was placed on the α parameter, a perfect binding model provided the best fit to the data for 7 of the 8 participants. There was no indication at all that α was affected by eccentricity or interitem distance. According to a location uncertainty model, such an effect would have been expected considering the higher probability of overlapping location distributions with increasing eccentricity and decreasing interitem distance.

Third, interitem distance and eccentricity strongly affected *sc* and *so,* whereas α was completely unaffected. Previous findings suggesting a change in the probability of correct feature binding with eccentricity and interitem distance might instead have been related to a change in the probability of discriminating the target from the nontarget. Actually, this idea is even likely considering that the probability that a certain letter is misperceived as being another letter (i.e., the probability that those letters are confused) has been found to increase with increasing retinal eccentricity and decreasing interitem distance (Appelman & Mayzner, 1982; Bouma, 1970, 1978; Krumhansl & Thomas, 1977; Polat & Sagi, 1994). Consequently, the ability to correctly discriminate the target from the nontarget is disturbed when elements are presented in closer vicinity. Nevertheless, the present conclusion stands in clear contrast to that of previous studies on feature binding (Ashby et al., 1996; Cohen & Ivry, 1989). Cohen and Ivry (1989), for instance, also found a dramatic increase in the difference between proportions of conjunction and feature errors when elements were presented adjacently to each other as opposed to far from each other. However, they ascribed this effect to location uncertainty (see Ashby et al., 1996, for a similar explanation). The results of the present experiment suggest that this effect might have been caused by changes in the probability of correctly discriminating the target from the nontarget.

Finally, as also evident from the proportions of correct responses in the LC and LO conditions, *c* was substantially higher than *o.* If the probability of perceiving the color is larger than the probability of perceiving the orientation, an imperfect binding model predicts the difference between the number of conjunction and feature errors to be larger in the LC condition than in the LO condition (see Figure 3). When imperfect binding occurs, the difference between the number of conjunction and feature errors is given by $[c \times c \times (1 - \alpha)] + [(1 - c) \times c \times (1 - \alpha)]$ in the LC condition and by $[o \times o \times (1 - \alpha)] + [(1 - o) \times o \times (1 - \alpha)]$ in the LO condition. If *c* is larger than *o,* it is expected that, in the LC condition, the difference between the number of conjunction and feature errors is larger than in the LO condition. However, a comparison of the data pattern in the LC condition with the pattern found in the LO condition showed that, if anything, the difference between the number of conjunction and feature errors tended to be smaller in the LC condition than in the LO condition.

In summary, Experiments 1 and 2 provide strong evidence in favor of a perfect binding model. Furthermore, the results show that the similarity of the values of the selection-relevant dimension is of crucial importance in determining whether or not a difference will be found between the number of conjunction and feature errors. If the values of the selection-relevant dimension are highly dissimilar, as in the case of color, the number of conjunction errors does not exceed the number of feature errors. In contrast, if the values of the selection-relevant dimension are similar, as in the case of orientation, the number of conjunction errors exceeds the number of feature errors. Obviously, the preceding inference is limited by at least one restriction. In Experiments 1 and 2, the dimension with the least similar values was always color, whereas the dimension with the most similar values was always orientation. If value similarity within dimensions is of crucial importance in the determination of the response pattern, it should be possible to reverse the data pattern by independently manipulating the similarity of the values of color and orientation. In Experiment 3, feature similarity was manipulated for color as well as orientation.

Experiment 3

The first two experiments tested the perfect binding model against the illusory conjunction model. In Experiment 3, the values of the dimensions color and orientation were independently varied to investigate whether or not the results of Experiments 1 and 2 are limited to the specific feature values used. The manipulation basically implied the independent variation of the similarity of the values corresponding to the color dimension and the values corresponding to the orientation dimension, resulting in four different stimulus sets (see Theeuwes, 1991, for a similar manipulation in a visual search task). Experiment 3 was similar to Experiment 1 with two differences. First, color similarity and orientation similarity were independently varied, resulting in four different stimulus sets. Second, as a means of reducing the required number of trials, instead of four conditions, only the OC condition and the CO condition were used.

If the previous results are not limited to the specific values of color and orientation used, the difference between the number of conjunction and feature errors is expected to be critically dependent on the similarity of the values of the selection-relevant dimension. Thus, independently of whether the selection-relevant dimension is color or orientation, if the probability of discriminating the target from the nontarget is large, the difference between the number of conjunction and feature errors should be smaller than if this probability is small. Furthermore, the probability of correct binding is expected to be independent of the stimulus material used. As in the previous experiments, the aim of the present experiment was to test the perfect binding model against the imperfect binding model.

Method

Participants. Eight participants took part in Experiment 3. All reported normal or corrected-to-normal vision.

Task and stimuli. As in the prior experiments, participants always performed in a primary and a secondary task. The primary task was identical to that of Experiment 1. In contrast to Experiment 1, only the OC condition and the CO condition were used for the secondary task. In addition, value similarity of color and orientation were independently varied. Similarity could be either low or high for both color and orientation.[7] The stimulus set corresponding to low color similarity and low orientation similarity (CLOL set) consisted of yellow (x, y = .397, .527) and blue (x, y = .214, .305) horizontal and vertical rectangles subtending 4 × 10 pixels (0.22° × 0.56° of visual angle). The stimulus set corresponding to low color similarity and high orientation similarity (CLOH set) consisted of yellow and blue horizontal and vertical rectangles subtending 5 × 8 pixels (0.28° × 0.45° of visual angle). The stimulus set corresponding to high color similarity and low orientation similarity (CHOL set) consisted of yellow and yellow-green (x, y = .329, .581) horizontal and vertical rectangles subtending 4 × 10 pixels (0.22° × 0.56° of visual angle). The stimulus set corresponding to high color similarity and high orientation similarity (CHOH set) consisted of yellow and yellow-green horizontal and vertical rectangles subtending 5 × 8 pixels (0.28° × 0.45° of visual angle). All elements had a luminance of approximately 70.0 cd/m^2. Furthermore, masks consisting of horizontal and vertical stripes subtended a visual angle of 0.58° in width and 0.64° in height. Note that the CLOH set corresponded exactly to the stimulus set used in Experiments 1 and 2.

Design. A within-subjects design was used. Independent variables were condition (OC condition vs. CO condition), color similarity (yellow–blue vs. yellow–yellow-green), and orientation similarity (5 × 8 pixels vs. 4 × 10 pixels). Independent variables were varied across blocks of trials. Condition was counterbalanced over participants, whereas stimulus set presentation sequence was determined according to a Latin square. Type of trial was again varied within blocks. Dependent variables were number of correct responses, number of conjunction errors, and number of feature errors.

Procedure. Each participant took part in one session of about 4 hr. A session consisted of eight blocks corresponding to all combinations of color similarity, orientation similarity, and condition. The sequence of blocks was such that half of the participants started with four blocks corresponding to the OC condition and the other half started with four blocks corresponding to the CO condition. The sequence in which the different stimulus sets were presented was determined by a Latin square. Each block consisted of a practice and an experimental part. Each practice part took about 20 min and consisted of 256 trials. During the first 128 practice trials the exposure duration was about 83 ms (i.e., 5 raster cycles), and during the second 128 trials the exposure duration was about 66 ms (i.e., 4 raster cycles). Each experimental part consisted of 128 trials with an exposure duration of approximately 50 ms (i.e., 3 raster cycles). Other procedures were identical to those of Experiment 1.

Results

Because participants rarely made any errors on the primary task (2.5% of trials or less), analyses concerning performance in the secondary task included all trials.

Response categories. Table 6 depicts the mean proportions of correct responses, the mean proportions of conjunction errors, and the mean proportions of feature errors as a function of stimulus set separately for the OC and CO conditions. The proportion of conjunction errors increased with increasing color similarity, $F(1, 7) = 140.06, p < .001$, and increasing orientation similarity, $F(1, 7) = 9.94$, $p < .016$. Furthermore, there was no difference in the proportions of conjunction errors between the CO condition and the OC condition, $F(1, 7) = 2.75, p > .050$. Neither color similarity nor orientation similarity interacted with condition: Color Similarity × Condition, $F(1, 7) = 0.04$, and Orientation Similarity × Condition, $F(1, 7) = 0.80$.

Table 6
Mean Proportions of Correct Responses, Conjunction Errors, and Feature Errors as a Function of Stimulus Set and Condition: Experiment 3

	CLOL		CLOH		CHOL		CHOH	
Category	OC	CO	OC	CO	OC	CO	OC	CO
Correct response	.93	.95	.89	.86	.72	.83	.69	.78
Conjunction error	.05	.02	.09	.07	.15	.13	.17	.16
Feature error	.02	.03	.02	.07	.14	.04	.14	.07

Note. Columns may not sum to 1.00 as a result of rounding errors. CLOL = low color and low orientation similarity; CLOH = low color and high orientation similarity; CHOL = high color and low orientation similarity; CHOH = high color and high orientation similarity. OC = orientation–color; CO = color–orientation.

An ANOVA on the mean individual proportions of feature errors showed that color similarity affected the number of feature errors in the OC condition, $F(1, 7) = 83.67$, $p < .001$, but not in the CO condition, $F(1, 7) = 1.16, p > .050$. Orientation similarity did not affect the number of feature errors in the OC condition, $F(1, 7) = 0.02$, but it did affect the number of feature errors in the CO condition, $F(1, 7) = 22.51, p < .002$.

Figure 4 depicts the average differences between the proportions of conjunction and feature errors separately for the OC condition and the CO condition. Generally, the proportion of conjunction errors did not exceed the proportion of feature errors if the similarity between the values of the selection-relevant dimension was low (i.e., if the target could be easily discriminated from the nontarget).

Theoretical analysis. Use of two instead of four conditions halved the available degrees of freedom for each model fit. Therefore, the number of free parameters had to be reduced accordingly. As in Experiments 1 and 2, fits were performed with models assuming $nrc = trc$ (denoted as c) and $nro = tro$ (denoted as o). Furthermore, sc was assumed to be equal to $2c - c^2$, and so was assumed to be equal to $2o - o^2$.[8] As a means of investigating whether the results are better described by an imperfect binding model or a perfect binding model, separate fits of both constrained models were

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[7] The similarity of orientation was indirectly varied by changing the length-to-width ratio of the rectangles. Directly varying the relative orientation of the rectangles while keeping the number of pixels constant was impossible because of limitations of the computer graphics.

[8] Because the target can be discriminated from the nontarget by (a) perceiving the target value of the selection-relevant dimension only, (b) perceiving the nontarget value of the selection-relevant dimension only, or (c) perceiving both values of the selection-relevant dimension, the probability of discriminating the target from the nontarget (i.e., sc and so) should be twice the value of the parameter corresponding to the reported feature minus the square of that value (i.e., $sc = 2c - c^2$ and $so = 2o - o^2$).

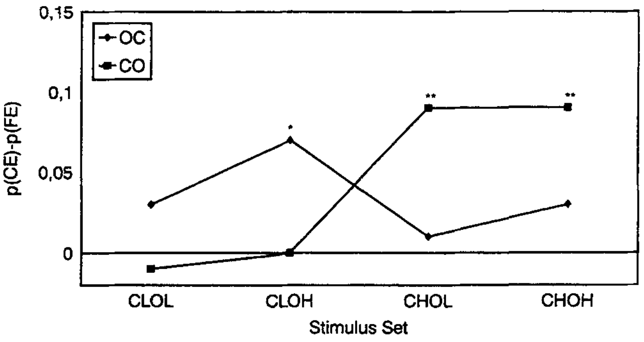

Figure 4. Mean differences between proportions of conjunction errors (CE) and feature errors (FE) as a function of stimulus set for the orientation–color (OC) and color–orientation (CO) conditions. CLOL = low color and low orientation similarity; CLOH = low color and high orientation similarity; CHOL = high color and low orientation similarity; CHOH = high color and high orientation similarity. *significantly larger than zero at .020; **significantly larger than zero at .001.

performed on the data of every participant. In Experiment 3, there were two conditions, two types of trials, two response categories per type of trial, and four stimulus sets, resulting in 32 cells in the data matrix per participant and 16 degrees of freedom.

Table 7 shows the individual maximum-likelihood estimates separately for the perfect and imperfect binding models and partial G^2 values ($df = 4$). For 6 of the 8 participants, the additional free parameters of the imperfect binding model did not provide a better fit to the data than the perfect binding model. Furthermore, for these 6 participants, the absolute fits of the perfect binding model accounted for about 99% of the variance in the data.

In general, α was not affected by color similarity, $F(1, 7) = 3.03$, $p > .050$, or by orientation similarity, $F(1, 7) = 2.61$, $p > .050$. The interaction was also not significant, $F(1, 7) = 0.03$. An ANOVA on the maximum-likelihood estimates of the perfect binding model showed that c was affected by color similarity, $F(1, 7) = 202.41$, $p < .001$, but not by orientation similarity, $F(1, 7) = 1.51$, $p > .050$.

Table 7
Individual Parameter Estimates From Best-Fitting Models and Partial G^2 Values: Experiment 3

Model and stimulus set–parameter	Participant							
	MR	WP	ED	EH	AP	YR	RB	JD
Imperfect binding model								
CLOL								
α	1.00	1.00	.95	.93	.98	1.00	1.00	.94
c	.97	.97	.95	.75	.83	.83	.93	1.00
o	.92	.95	1.00	.84	.76	.93	.94	.93
CLOH								
α	1.00	.94	.79	.83	1.00	.95	1.00	.88
c	.98	1.00	.92	.75	.83	.82	.93	.95
o	.81	.85	.90	.54	.43	.75	.89	.81
CHOL								
α	1.00	1.00	.83	1.00	.89	1.00	.96	.81
c	.53	.54	.82	.26	.36	.29	.34	.69
o	.60	.96	1.00	.56	.51	.80	.95	.91
CHOH								
α	1.00	1.00	.74	.63	1.00	1.00	1.00	.65
c	.58	.55	.67	.38	.29	.26	.38	.64
o	.76	.69	.94	.53	.29	.68	.87	.76
Perfect binding model								
CLOL								
c	.97	.97	.88	.67	.81	.83	.93	.92
o	.92	.95	.98	.82	.75	.93	.94	.90
CLOH								
c	.98	.99	.66	.67	.83	.79	.93	.82
o	.81	.74	.80	.42	.43	.71	.89	.72
CHOL								
c	.53	.54	.56	.26	.32	.29	.32	.50
o	.60	.96	1.00	.56	.48	.80	.94	.86
CHOH								
c	.58	.55	.40	.25	.29	.26	.38	.38
o	.76	.69	.88	.43	.29	.68	.87	.57
Partial G^2	0.00	4.43	36.68**	5.25	0.30	0.49	0.04	24.57**

Note. CLOL = low color and low orientation similarity; α = probability of correct binding; *c* = probability of perceiving the color; *o* = probability of perceiving the orientation; CLOH = low color and high orientation similarity; CHOL = high color and low orientation similarity; CHOH = high color and high orientation similarity.
$^{**}p < .01$.

The interaction was not significant, $F(1, 7) = 0.50$. The maximum-likelihood estimate of o was affected by both color similarity, $F(1, 7) = 7.25$, $p < .031$, and orientation similarity, $F(1, 7) = 21.01$, $p < .003$. However, the interaction was not significant, $F(1, 7) = 2.54$, $p > .050$.

Discussion

Experiment 3 shows that the difference between the number of conjunction and feature errors dramatically depends on the similarity of the values of the selection-relevant dimension.[9] If the similarity of the values of the selection-relevant dimension is low (i.e., in the CO condition of the CLOL and CLOH sets and the OC condition of the CLOL and CHOL sets), there is no difference between the number of conjunction and feature errors. In the case of high similarity between the values of the selection-relevant dimension, there was a substantial difference between the number of conjunction and feature errors, except in the OC condition of the CHOH set. The absence of a significant difference in the OC condition of the CHOH set might have been caused by the relatively low estimate of o.

For 6 of the 8 participants, the additional free parameter of the imperfect binding model did not provide a significant improvement in fit over the more parsimonious perfect binding model. This implies that the results in Experiments 1 and 2 are not limited to the specific values of color and orientation. It is important to note that in Experiment 3, in contrast to Experiments 1 and 2, model fits were based on the OC and CO conditions only. The finding that the perfect binding model outperformed the imperfect binding model for 6 of the 8 participants is even more striking if one considers that omitting the LC and LO conditions might have produced a systematic underestimation of α. Decreasing the number of conditions necessarily required a reduction in the number of free parameters. In Experiment 3, the number of free parameters was reduced by assuming sc to be equal to $2c - c^2$ and so to be equal to $2o - o^2$. In this way, the values of sc and so were strongly constrained by the values of c and o, respectively. Because preattentive selective tuning was possible in the OC and CO conditions but not in the LC and LO conditions, estimates of c and o based on the OC and CO conditions only might be larger than estimates based on all four conditions (Cave & Wolfe, 1990; Wolfe, 1994; Wolfe et al., 1989).

Indeed, additional fits of the data of Experiments 1 and 2 revealed that c and o based on model fits with the CO and OC conditions only were generally higher than c and o based on model fits with all four conditions. It is plausible that selective tuning might have also occurred in Experiment 3. Because sc and so are dependent on c and o, estimates of their size may have become larger than their actual size, with the consequence that the estimates of α may have become smaller than was actually the case. Basically, the finding that the maximum-likelihood estimate of o was dependent not only on orientation similarity but also on color similarity suggests indeed that selective tuning occurred, at least in those conditions in which a highly dissimilar color served as the selection dimension. That is, participants might have been able to selectively tune the system to the perception of yellow in the conditions with yellow and blue, whereas this might not have been possible in the conditions with yellow and yellow-green. As a result, the values of o and consequently the values of so might have been higher in the conditions in which color similarity was low than in the conditions in which color similarity was high.

Experiments 1–3 provide ample evidence in favor of a perfect binding account. This evidence is based not only on a different paradigm but also on the use of different stimuli. Previous studies on interdimensional conjunctions have typically used letters as stimuli. Perhaps, the stimuli in Experiments 1–3 were simply not suited to elicit illusory conjunctions. Therefore, a fourth experiment was executed that was basically a replication of Experiment 1 with one major difference. Instead of rectangles, letters similar to those used by Ashby et al. (1996) were used as stimuli.

Experiment 4

Method

Participants. Eight participants took part in the present experiment. All had normal or corrected-to-normal vision.

Task and stimuli. The tasks and stimuli in Experiment 4 were the same as in Experiment 1, except that the colored stimuli used in the secondary task were different. Basically, the vertical rectangle was substituted by the letter *T* and the horizontal rectangle was substituted by the letter *X* (0.38° of visual angle in width and 0.51° of visual angle in height at an observation distance of 0.45 m). Furthermore, the color yellow was substituted by the color red (21.1 cd/m^2), and the color blue was substituted by the color green (21.0 cd/m^2). As a result, the four conditions were modified accordingly (i.e., orientation was substituted by identity). In the identity–color condition (IC condition), participants were to indicate the color of the *T*, which could be either red or green. In the location–color condition (LC condition), participants were to indicate the color of the upper letter, which could be red or green. In the color–identity condition (CI condition), participants were to indicate the identity of the red element, which could be either *T* or *X*. In the location–identity condition (LI condition), participants were to indicate the identity of the upper letter, which could be *T* or *X*. Background luminance was about 6.0 cd/m^2, and the luminance of the mask was about 80.1 cd/m^2. Further details were the same as in Experiment 1.

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[9] It is curious that the findings of Experiment 4 are completely opposite to earlier findings of Ivry and Prinzmetal (1991). Ivry and Prinzmetal (1991) had participants report the color of a target letter (*X* or *T*) that was concurrently presented with a colored nontarget letter (*O* or *S*). Thus, color was the response-relevant dimension. Their critical manipulation involved the degree of similarity between the target color and the nontarget color. Their basic finding was that the difference between the number of conjunction and feature errors was larger when color values were more similar. In Experiment 4, when color was the response-relevant dimension, enhancing color similarity resulted in a profound decrease in the difference between the number of conjunction and feature errors. Because the experiments of Ivry and Prinzmetal (1991) differed in many respects from the present study, it is difficult to determine why these findings diverge.

Design. The design was the same as in Experiment 1.

Procedure. The procedure was the same as in Experiment 1, except that the experimental part of each condition consisted of 128 trials instead of 258 trials.

Results

The primary task was included to ensure that participants attended to and fixated on the center of the display during task performance. Because digit reports were verbal, errors on the primary task were extremely rare for all participants. Analyses of performance in the secondary task included all trials.

Response categories. Table 8 depicts the mean proportions of correct responses, the mean proportions of conjunction errors, and the mean proportions of feature errors as a function of condition. Average proportions of correct responses showed that performance was better in the LC condition than in the LI condition, $F(1, 7) = 68.06$, $p < .001$, indicating that observers were better in discriminating red from green than in discriminating the *T* from the *X*. Furthermore, the proportion of correct responses was higher in the LC condition than the IC condition, $F(1, 7) = 12.19$, $p < .01$, and lower in the LI condition than in the CI condition, $F(1, 7) = 31.05, p < .001$.

A MANOVA on the mean individual differences between the proportions of conjunction and feature errors showed a significant effect of condition, $F(3, 5) = 27.65$, $p < .002$. The number of conjunction errors was larger than the number of feature errors in the IC condition, $F(1, 7) = 41.73, p < .001$. Such a difference was not present in the CI condition, $F(1, 7) = 0.02$, or the LI condition, $F(1, 7) = 0.02$. In the LC condition, the number of feature errors even exceeded the number of conjunction errors, $F(1, 7) = 8.92$, $p < .02$.

Theoretical analysis. As a means of investigating whether the present data are better described by a model assuming imperfect feature binding or perfect feature binding, both models were separately fit to the data of each participant. In Experiment 4, the conditions were the same as in Experiment 1, except that orientation was replaced by identity. As a result, the labels of the parameters *so*, *tro*, and *nro* were changed to *si* (the probability of discriminating the target from the nontarget on the basis of identity), *tri* (the probability of perceiving the target identity), and *nri* (the probability of perceiving the nontarget identity), respectively.

As in Experiment 1, there were four conditions (IC, LC, CI, and LI), two types of trials (different and identical), and two possible responses per type of trial. Consequently, there were 16 cells in the data matrix for each participant ($4 \times 2 \times 2$) and 8 degrees of freedom.

The imperfect and perfect binding models were separately fit either assuming all parameters to be free or constraining the values corresponding to the nonreported features to equal the values of the corresponding reported features, that is, assuming $nrc = trc$ (denoted as c) and $nri = tri$ (in the following denoted as i, the probability of perceiving the identity). For each participant, constraining the values of the nonreported features to those of the reported features did not affect the goodness of fit, as evident from the partial G^2 value ($df = 2$). Furthermore, there was no difference in the probability of correct binding, α, when the fits of the constrained models were compared with those of the unconstrained models. Therefore, in the following, the reported model fits are those performed with models in which $nrc = trc$ (denoted as c) and $nri = tri$ (denoted as i) unless reported differently (see also Ashby et al., 1996, p. 183).

The constrained imperfect binding model and the perfect binding model were separately fit to the data of each individual participant. Table 9 depicts the individual maximum-likelihood estimates separately for the perfect binding model and the imperfect binding model, along with partial G^2 values ($df = 1$). For every participant, the additional free parameter of the imperfect binding model did not provide a significant improvement in fit over the more parsimonious perfect binding model.[10] Basically, for every participant, α was equal to 1. The absolute fits of the perfect binding model were very good. On average, the perfect binding model accounted for about 95% of the variance in the data.

Additional fits were performed in which α was fixed at a value of .95, yielding an imperfect binding model with the same number of free parameters as the perfect binding model. A direct comparison of $-2lnL$ showed that the perfect binding model provided a much better fit to the data than the imperfect binding model for every participant. An ANOVA on the parameter estimates of the perfect binding model showed that *sc* and *c* were larger than *si* and *i*, $F(1, 7) = 52.17, p < .001$.

Table 8
Mean Proportions of Correct Responses, Conjunction Errors, and Feature Errors as a Function of Condition: Experiment 4

	Condition			
Category	IC	LC	CI	LI
Correct response	.82	.95	.83	.69
Conjunction error	.13	.01	.09	.15
Feature error	.05	.04	.09	.15

Note. Columns may not sum to 1.00 as a result of rounding errors. IC = identity–color; LC = location–color; CI = color–identity; LI = location–identity.

Discussion

The results of Experiment 4 show that the use of letter stimuli basically yields the same pattern of results as the use of rectangles. For every participant, the perfect binding model provided the best fit to the data, implying again that illusory conjunctions do not exist and that the results of

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[10] Comparing fits of models with all parameters free with those of models in which the values of the nonreported features were equal to the values corresponding to the reported features revealed that the constrained models provided a better overall fit to the data than the unconstrained models. Furthermore, α estimates were not affected.

Table 9
Individual Parameter Estimates From Best-Fitting Models and Partial G^2 Values: Experiment 4

Model and parameter	Participant							
	IB	MD	RG	SP	LM	WR	MK	BW
Imperfect binding model								
α	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
sc	1.00	1.00	1.00	.94	1.00	1.00	1.00	1.00
c	.76	.86	.95	.96	.84	.96	.98	.85
si	.37	.64	.73	.62	.59	.58	.86	.73
i	.08	.42	.62	.57	.70	.48	.70	.61
Perfect binding model								
sc	1.00	1.00	1.00	.94	1.00	1.00	1.00	1.00
c	.76	.86	.95	.96	.84	.96	.98	.85
si	.37	.64	.73	.62	.59	.58	.86	.73
i	.08	.42	.62	.57	.70	.48	.70	.61
Partial G^2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note. α = probability of correct binding; *sc* = probability of discriminating the target from the nontarget on the basis of color; *c* = probability of perceiving the color; *si* = probability of discriminating the target from the nontarget on the basis of identity; *i* = probability of perceiving the identity.

previous studies suggesting the existence of illusory conjunctions were actually due to errors of target–nontarget confusion. However, the entire pattern of results obtained in the first four experiments would not be very interesting if it were the case that those stimuli would not lead to an excess of conjunction errors over feature errors when used in a mainstream paradigm. The stimuli of Experiments 1–3 were obviously considerably different from those used in previous studies, and even the letter stimuli of Experiment 4 might have been slightly different from those used in previous studies. Consequently, it is still theoretically possible that the specific stimuli used in Experiments 1–4 do not, in general, produce data patterns suggesting the existence of illusory conjunctions. As a means of enabling further generalization, a fifth experiment was performed in which the stimuli of Experiments 1–4 were used in a mainstream task.

Experiment 5

In Experiment 5, a typical mainstream task was used. Participants were simultaneously presented with one of two possible targets and one of two possible nontargets. Target color and nontarget color were sampled randomly and without replacement from a set of three colors. Participants had the task of reporting the identity and color of the target. There were two conditions in Experiment 5. In one condition the rectangles of Experiment 1–3 were used, whereas in the other condition the letter stimuli of Experiment 4 were used.

Method

Participants. Six participants took part in Experiment 5. All had normal or corrected-to-normal vision.

Task and stimuli. Stimuli were presented on a Low Radiation MPR-II monitor controlled by a 486DX2 PC. The stimulus display always consisted of a central white fixation point and two peripherally presented colored elements that were surrounded by two white dollar sign elements on a black background. It was equally probable that the four elements were located above or below the fixation point. The eccentricity of element presentation was 4.83° of visual angle at an observation distance of 0.45 m. The center-to-center distance between elements was 1.02°. At each presentation, the target was randomly selected from a target set of two elements, and the nontarget was randomly selected from a nontarget set of two elements. The colors of the target and nontarget were randomly selected from a set of three colors (red, green, and blue, approximately 21.0 cd/m^2) with the constraint that, in one presentation, target and nontarget could not have the same color.

In the letter condition, the target set consisted of *T* and *X* and the nontarget set consisted of *C* and *S*. Letters in both sets had a width of 0.38° of visual angle and a height of 0.51° of visual angle. In the rectangle condition, the target set consisted of a vertical and a horizontal rectangle of 5 × 8 pixels (0.28° × 0.45° of visual angle). The nontarget set consisted of a vertical and a horizontal rectangle of 4 × 10 pixels (0.22° × 0.56° of visual angle). Stimuli were presented on a black background (0.8 cd/m^2). The flanking dollar signs (0.38° of visual angle in width and 0.57° of visual angle in height) had a luminance of 80.1 cd/m^2. After presentation, stimuli were masked by a uniform white rectangle subtending 4.89° of visual angle in width and 1.91° of visual angle in height, with a luminance of 80.1 cd/m^2.

In each condition, the task of participants was to indicate the color and identity of the target element by pressing one of six possible response keys on the computer keyboard (i.e., Insert, Delete, Pos1, End, Page Up, and Page Down). Each key corresponded to one unique combination of target color and target identity.

Design. A within-subjects design was used. Participants performed in both conditions, which were presented in separate blocks. Each block consisted of a practice and an experimental part. The sequence of condition presentation was counterbalanced over participants. The dependent variable was the number of responses in each possible response category. There were six possible response categories (see Ashby et al., 1996): correct response (C); color conjunction error, identity correct (CR); color feature error, identity correct (CF); color correct, identity feature error (LF);

color conjunction error, identity feature error (LFCR); and color feature error, identity feature error (CLF).

Procedure. Each trial started with the presentation of a tone (1000 Hz, 200 ms) immediately followed by the presentation of a fixation point in the middle of the screen. After 1 s, the stimulus display was presented. After approximately 83 ms (i.e., 5 raster cycles), stimulus elements were masked until a manual response was given. If the response was correct, 1 s afterward the next trial started. If the response was incorrect, the word "FOUT" (wrong) appeared on the screen during 500 ms, followed by an interval of 1 s before the next trial started. Because the Experiment 5 task proved to be more difficult, exposure duration was enhanced in comparison with the exposure duration in Experiments 1–4.

Each participant performed in two blocks corresponding to the two conditions during one session of about 2 hr. Each block consisted of a practice and an experimental part. The practice part consisted of 192 (2 × 96) trials. Display presentation times were approximately 116 ms (i.e., 7 raster cycles) during the first 98 practice trials and about 83 ms (i.e., 5 raster cycles) during the second 98 practice trials. The subsequent experimental part consisted of 288 trials, in which the time of display presentation was approximately 83 ms. Participants were free to take a break during and between blocks.

Results

Response categories. The mean response proportions per condition are presented in Table 10. In the letter condition, there was a higher proportion of color conjunction errors (CR and LFCR) than color feature errors (CF and CLF), $F(1, 5) = 11.71, p < .019$. This was also the case in the rectangle condition, $F(1, 5) = 27.31, p < .003$. Generally, the two conditions were equal with respect to proportion of correct responses, $F(1, 5) = 4.72, p > .50$; proportion of color conjunction errors (CR and LFCR), $F(1, 5) = 3.83, p > .050$; proportion of color feature errors (CF and CLF), $F(1, 5) = 0.27$; and proportion of identity feature errors (LF, LFCR, and CLF), $F(1, 5) = 4.66, p > .050$.

Theoretical analysis. As means of investigating whether the results are better described by a model assuming imperfect binding or perfect binding, the alpha model (see Figure 5) developed by Ashby et al. (1996) was separately fit to the data of each condition for each individual participant, with the value of α variable (imperfect binding model) or fixed at 1 (perfect binding model). Although the partial report design used in Experiment 5 placed tight constraints on the parameter estimates for the probability of perceiving the target color (T_C), the probability of perceiving the target identity (T_L), and α, it placed only weak constraints on the estimates of the probability of perceiving the nontarget color (N_C) and the probability of perceiving the nontarget identity (N_L; see also Ashby et al., 1996). Therefore, values of N_C and N_L were equalized to the reported feature values and denoted TN_C (the probability of perceiving the color) and TN_L (the probability of perceiving the identity), respectively (i.e., $N_C = T_C = TN_C$ and $N_L = T_L = TN_L$).

Table 10
Mean Proportions of Responses as a Function of Condition: Experiment 5

Response	Condition Letter	 Rectangle
C	.68	.52
CR	.13	.17
CF	.03	.03
LF	.09	.12
LFCR	.06	.14
CLF	.01	.02

Note. Columns may not sum to 1 as a result of rounding errors. C = correct response; CR = color conjunction error, identity correct; CF = color feature error, identity correct; LF = color correct, identity feature error; LFCR = color conjunction error, identity feature error; CLF = color feature error, identity feature error.

In Experiment 5, there were two possible stimulus positions (bottom and top) and six response categories per position, resulting in 12 cells in the data matrix per condition per participant and 10 degrees of freedom. Individual maximum-likelihood estimates, separately for the perfect and imperfect binding models, and partial G^2 values ($df = 1$) are depicted in Table 11. For the letter condition, the imperfect binding model provided the best fit to the data for every participant. For the rectangle condition, the imperfect binding model provided the best fit to the data for 5 of the 6 participants.[11] A comparison of the parameter estimates of the imperfect binding model between the letter condition and the rectangle condition showed no difference between the estimates of α, $F(1, 5) = 2.09, p > .050$; no difference between the estimates of TN_L, $F(1, 5) = 5.14, p > .050$; and no difference between the estimates of TN_C, $F(1, 5) = 1.64, p > .050$.

Discussion

The intention of Experiment 5 was to investigate whether it would be possible to obtain data patterns suggesting the existence of illusory conjunctions with the stimuli of Experiments 1–4. Basically, the results were very straightforward. In both the letter condition and the rectangle condition, participants committed more color conjunction errors than color feature errors. Application of the more rigorous theoretical method developed by Ashby et al. (1996) showed that a model assuming imperfect binding provided the best fit to the data in both conditions. In general, the results of the present experiment are remarkably similar to those found in previous studies on illusory conjunctions (e.g., Ashby et al., 1996; Cohen & Ivry, 1989). However, considering the results of Experiments 1–4 makes it difficult to believe that the findings of Experiment 5 really are related to illusory conjunctions. Whereas the paradigm used in Experiments 1–4 enables one to distinguish between errors of target–nontarget confusion and errors of feature binding, the paradigm of Experiment 5 does not. As a consequence, the estimate of the probability of correct binding might have

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[11] Alternative data fits performed with the alpha model of Ashby et al. (1996), modified to account for possible similarity among the alternative target values, resulted in α estimates similar to those of the original alpha model (see Ashby et al., 1996, p. 187).

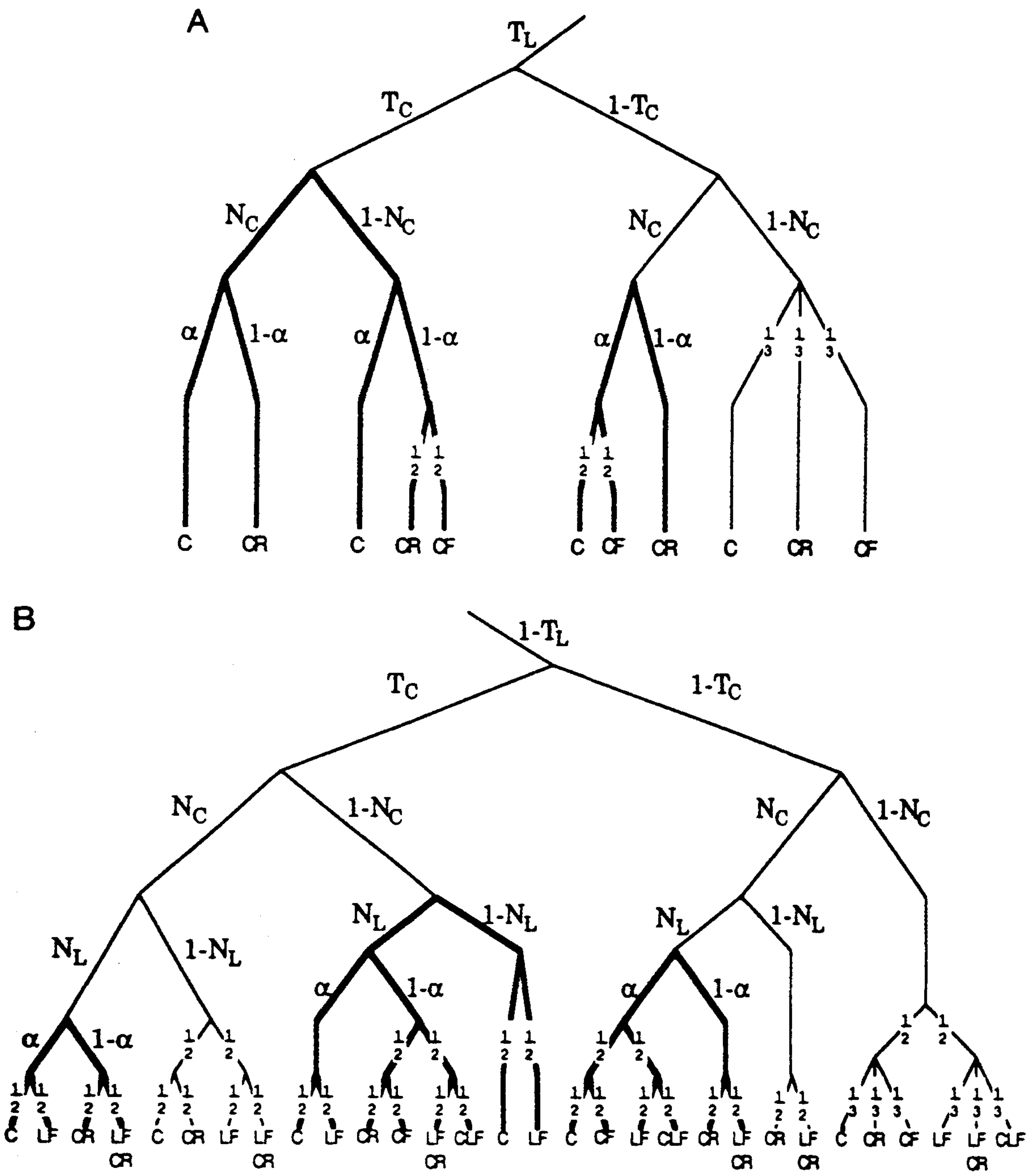

Figure 5. The alpha model of Ashby et al. (1996). T_C = probability of perceiving the target color; T_L = probability of perceiving the target identity; N_C = probability of perceiving the nontarget color; N_L = probability of perceiving the nontarget identity; α = probability of correct binding; C = correct response; CR = color conjunction error, identity correct; CF = color feature error, identity correct; LF = color correct, identity feature error; LFCR = color conjunction error, identity feature error; CLF = color feature error, identity feature error. (From "A Formal Theory of Feature Binding in Object Perception," by Ashby et al., 1996, *Psychological Review*, *103*, p. 173. Copyright 1996 by the American Psychological Association. Adapted with permission.)

Table 11
Individual Parameter Estimates From Best-Fitting Models and Partial G^2 *Values: Experiment 5*

	Participant					
Model and parameter	MD	SS	LM	MS	CS	JV
			Letter			
Imperfect binding model						
α	.83	.89	.85	.95	.81	.87
TN_C	.98	.98	.88	.92	.86	.78
TN_L	.82	.43	.57	.97	.38	.91
Perfect binding model						
TN_C	.97	.97	.83	.78	.82	.53
TN_L	.51	.34	.41	.97	.25	.90
Partial G^2	67.44**	4.15*	15.13**	26.55**	6.93**	25.25**
			Rectangle			
Imperfect binding model						
α	.95	.87	.87	.70	.26	.70
TN_C	.96	.86	.85	.95	.56	.82
TN_L	.56	.64	.41	.45	.13	.41
Perfect binding model						
TN_C	.95	.81	.81	.91	.47	.73
TN_L	.50	.49	.31	.22	.00	.22
Partial G^2	2.94	14.41**	4.40*	22.38**	7.44**	15.71**

Note. α = probability of correct binding; TN_C = probability of perceiving the color; TN_L = probability of perceiving the identity.
$^* p < .05$. $^{**} p < .01$.

been contaminated by errors of target–nontarget confusion, because no parameter in the alpha model of Ashby et al. (1996) can account for such errors. A sixth experiment was executed to directly investigate the effects of target–nontarget similarity on the probability of correct feature binding.

Experiment 6

If performance in a mainstream paradigm depends on the similarity of the values of the selection-relevant dimension, varying the similarity of the values of the selection-relevant dimension should affect both the response pattern of observers and the estimates of the probability of correct binding. Experiment 6 was designed to test this hypothesis by varying the similarity of the values of the selection-relevant dimension without changing the similarity among the alternative targets or among the alternative nontargets. In contrast to Ashby et al. (1996), colors were equiluminant and, instead of letters, geometrical figures of equal numbers of pixels were used.

Method

Participants. Eight participants took part in the present experiment. All had normal or corrected-to-normal vision.

Task and stimuli. Stimuli were presented on a Sony Multiscan HG monitor controlled by a 386 Hewlett-Packard PC. The stimulus display always consisted of a central white fixation point and two colored elements surrounded by two white dollar sign elements (80.1 cd/m^2, subtending a visual angle of 0.80° in width and 1.26° in height) on a black background (0.8 cd/m^2). It was equally probable that the four elements were located above or below the central fixation point. Eccentricity of element presentation was 4.57° of visual angle at an observation distance of 0.50 m. The center-to-center distance between elements was 1.26° of visual angle.

The task of participants was to indicate the color and identity of the target element, which was either a symmetric vertical bar with two small stripes above its center or a symmetric vertical bar with two small stripes below its center. The nontargets were always asymmetric. In one condition, the low similarity condition, the nontarget element was either an asymmetrical horizontal bar with one small stripe at the upper left side and one small stripe at the lower right side or an asymmetrical horizontal bar with one small stripe at the upper right side and one small stripe at the lower left side. In the other condition, the high similarity condition, the nontarget element was either an asymmetrical vertical bar with one small stripe at the upper left side and one small stripe at the lower right side or an asymmetrical vertical bar with one small stripe at the upper right side and one small stripe at the lower left side (see Figure 6). Both targets and nontargets extended 0.80° × 1.09° of visual angle. Target and nontarget colors were always randomly determined from a set of three equiluminant colors (i.e., red, green, and blue, with a luminance of 21.0 cd/m^2), with the constriction that the target and nontarget never had the same color. Stimulus displays were presented during about 66 ms (i.e., 4 raster cycles) and masked afterward with a horizontal white rectangle subtending a visual angle of 5.71° in width and 1.72° in height with a luminance of 80.1 cd/m^2.

Design. A within-subjects design was used. Participants performed in both the low similarity condition and the high similarity condition, which were presented in two separate blocks. Each block consisted of a practice and an experimental part. The sequence of condition presentation was counterbalanced over

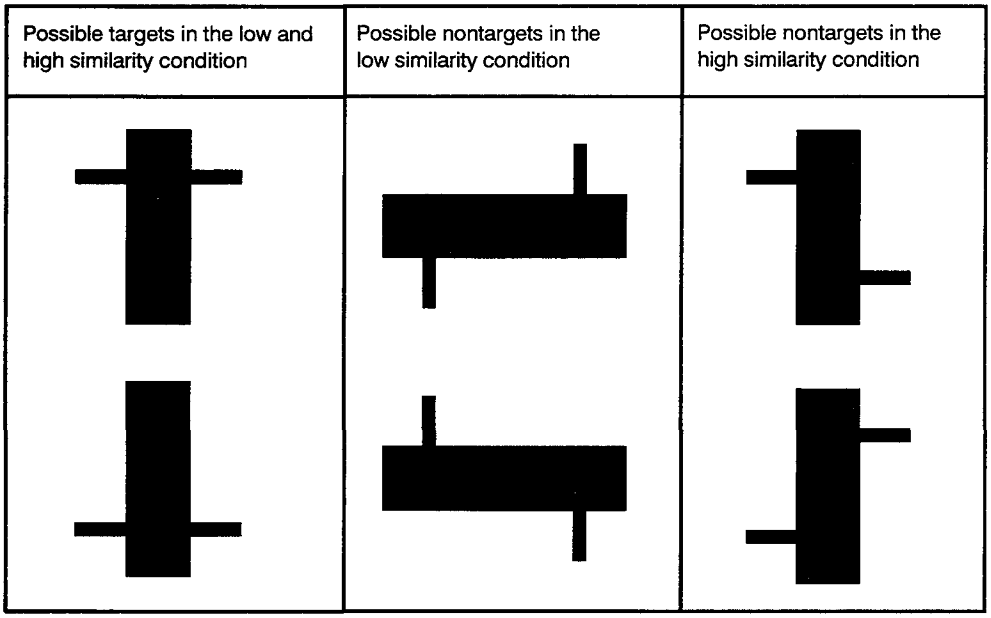

Figure 6. The stimulus sets used in Experiment 6. In the experiment, elements were of different colors (i.e., instead of black).

participants. The dependent variable was the number of responses in each possible response category (see Experiment 5).

Procedure. Each trial started with the presentation of a tone (1000 Hz, 200 ms) immediately followed by the presentation of a fixation point in the middle of the screen. After 1 s, the stimulus display was presented. After approximately 66 ms, stimulus elements were masked until a manual response was given. If the response was correct, 1 s afterward the next trial started. If the response was incorrect, the word "FALSCH" (wrong) appeared on the screen during 500 ms followed by an interval of 1 s before the next trial started.

Each participant performed in two blocks corresponding to the two conditions during one session of about 2 hr. Each block consisted of a practice and an experimental part. The practice part consisted of 196 (2 × 98) trials. Display presentation times were about 116 ms (i.e., 7 raster cycles) during the first 98 practice trials and 66 ms (i.e., 4 raster cycles) during the second 98 practice trials. The subsequent experimental part consisted of 288 trials in which the time of display presentation was 66 ms (i.e., 4 raster cycles). Participants were free to take a break during and between blocks.

Results

Response categories. Mean response proportions, separately for the low similarity and high similarity conditions, are depicted in Table 12. The proportion of color conjunction errors (CR and LFCR) exceeded the proportion of color feature errors (CF and CLF) in the low similarity condition, $F(1, 7) = 7.63$, $p < .028$, as well as the high similarity condition, $F(1, 7) = 279.82$, $p < .001$. However, the distribution of responses over the six categories was not the same in both conditions. The proportion of correct responses was considerably higher in the low similarity condition than in the high similarity condition, $F(1, 7) = 49.49$, $p < .001$. The proportion of color conjunction errors (CR and LFCR) was substantially lower in the low similarity condition than in the high similarity condition, $F(1, 7) = 76.63$, $p < .001$. The proportions of color feature errors (CF and CLF) did not differ between the low similarity condition and the high similarity condition, $F(1, 7) = 1.57$, $p > .050$. Finally, there was no significant difference in the proportions of identity feature errors (LF, LFCR, and CLF) between the low similarity condition and the high similarity condition, $F(1, 7) = 4.37$, $p > .050$.

Theoretical analysis. As a means of investigating whether the results are better described by a model assuming imperfect binding or perfect binding, the same procedures were followed as in Experiment 5 (see Results section of Experiment 5). Table 13 depicts the individual maximum-likelihood estimates separately for the perfect and imperfect binding models, along with partial G^2 values ($df = 1$). In the

Table 12
Mean Proportions of Responses as a Function of Target–Nontarget Similarity: Experiment 6

Response	Target–nontarget similarity	
	Low	High
C	.66	.41
CR	.05	.26
CF	.01	.01
LF	.23	.14
LFCR	.05	.17
CLF	.01	.00

Note. Columns may not sum to 1 as a result of rounding errors. C = correct response; CR = color conjunction error, identity correct; CF = color feature error, identity correct; LF = color correct, identity feature error; LFCR = color conjunction error, identity feature error; CLF = color feature error, identity feature error.

Table 13
Individual Parameter Estimates From Best-Fitting Models and Partial G^2 Values: Experiment 6

Model and parameter	Participant							
	MD	JD	UR	MB	JE	AH	TR	AZ
				Low similarity				
Imperfect binding model								
α	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.96
TN_C	.97	.98	.99	.81	.84	.96	.99	.95
TN_L	.77	.80	.69	.28	.34	.58	.40	.43
Perfect binding model								
TN_C	.97	.98	.99	.81	.84	.96	.99	.95
TN_L	.77	.80	.69	.28	.34	.58	.40	.40
Partial G^2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84
				High similarity				
Imperfect binding model								
α	.63	.67	.60	.47	.57	.59	.58	.86
TN_C	.99	.93	.98	.89	.89	.99	.97	.95
TN_L	.47	.65	.40	.16	.23	.42	.11	.35
Perfect binding model								
TN_C	.98	.87	.96	.80	.79	.98	.94	.93
TN_L	.17	.27	.13	.03	.07	.13	.03	.26
Partial G^2	46.78**	87.44**	36.65**	8.59**	10.65**	44.04**	2.25	4.76*

Note. α = probability of correct binding; TN_C = probability of perceiving the color; TN_L = probability of perceiving the identity.
*$p < .05$. **$p < .01$.

low similarity condition, for every participant, the imperfect binding model did not provide an improvement in fit over the more parsimonious perfect binding model. In the high similarity condition, the imperfect binding model provided the best fit to the data for 7 of the 8 participants. An ANOVA on the estimates of the imperfect binding model showed that the estimate of α was dramatically affected by similarity, $F(1, 7) = 72.04, p < .001$.

In Experiment 6, the similarity among the alternative feature values was relatively high. One consequence of high feature similarity is that the all-or-none assumption of the alpha model will no longer be valid (Ashby et al., 1996). As a means of addressing the possibility that limited information about the target identity is insufficient to know what the target is, alternative data fits were performed with the alpha model of Ashby et al. (1996), modified to account for possible similarity among the alternative target values (see Ashby et al., 1996, p. 187). Basically, the modification implied that T_L was now equal to the probability that at least some information about the target identity was obtained. In addition, the T_L branches of the tree structure of the alpha model were extended to include two additional branches: one branch corresponding to the probability that the target was identified as one identity (Ta_L) and the other branch corresponding to the probability that the target was identified as the other identity (Tb_L). Ta_L and Tb_L differed depending on whether the display contained one or the other target. Consequently, the numbers of responses per response category were separately calculated for each target presented. In Experiment 6, there were two stimulus positions (bottom and top), two types of targets, and six response categories, resulting in 20 degrees of freedom. The best fits of the models were obtained by assuming $N_L = .50$, $N_C = T_C$ (denoted as TN_C, the probability of perceiving the color), and $Ta_L = Tb_L$ (denoted as Tab_L, the probability of perceiving a certain target identity given the presentation of that identity).

Consequently, after parameter estimation, there were 16 degrees of freedom for the imperfect binding model and 17 degrees of freedom for the perfect binding model. The individual and mean parameter estimates from the best-fitting modified alpha models with their corresponding partial G^2 values ($df = 1$) are shown in Table 14. Generally, there was strong agreement among the alpha models and the modified alpha models. For 7 participants, the additional free parameter of the imperfect binding model did not provide a significant improvement in fit over the more parsimonious perfect binding model in the low similarity condition. However, in the high similarity condition, the imperfect binding model clearly outperformed the perfect binding model.

An ANOVA on the estimates of the imperfect binding model showed that the estimate of α was dramatically affected by similarity, $F(1, 7) = 77.57$, $p < .001$. The estimates of the other parameters were not affected: N_L, $F(1, 7) = 0.36$; TN_C, $F(1, 7) = 1.51$; and Tab_L, $F(1, 7) = 0.93$.

Discussion

The aim of Experiment 6 was to determine to what extent target–nontarget similarity affects the alpha estimates in a typical illusory conjunction experiment. The results of Experiment 6 show that performance strongly depends on the similarity between the target and the nontarget. If

Table 14
Individual Parameter Estimates From Best-Fitting Modified Models and Partial G^2 Values: Experiment 6

Model and parameter	Participant							
	MD	JD	UR	MB	JE	AH	TR	AZ
				Low similarity				
Imperfect binding model								
α	1.00	1.00	.99	1.00	1.00	1.00	1.00	.93
TN_C	.97	.98	.99	.83	.85	.97	.99	.96
T_L	.96	1.00	.97	.15	.30	.81	.62	.46
Tab_L	.87	.87	.80	.97	.85	.77	.61	1.00
Perfect binding model								
TN_C	.97	.98	.99	.83	.85	.97	.99	.95
T_L	.96	.99	.94	.15	.29	.81	.62	.40
Tab_L	.87	.87	.81	.97	.85	.77	.61	1.00
Partial G^2	0.00	1.06	0.69	0.00	0.00	0.00	0.00	6.21*
				High similarity				
Imperfect binding model								
α	.63	.69	.59	.49	.51	.58	.51	.80
TN_C	.99	.93	.99	.94	.95	.99	.99	.95
T_L	.48	.67	.40	.16	1.00	.43	1.00	.38
Tab_L	1.00	1.00	1.00	1.00	.61	1.00	.55	1.00
Perfect binding model								
TN_C	.99	.83	.97	.88	.85	.99	.98	.94
T_L	.16	.36	.00	.00	.00	.08	.00	.25
Tab_L	1.00	1.00	.82	.63	.71	1.00	.64	1.00
Partial G^2	136.65**	144.37**	134.90**	112.73**	110.42**	145.01**	108.56**	35.35**

Note. α = probability of correct binding; TN_C = probability of perceiving the color; T_L = probability of perceiving at least some information concerning the identity; Tab_L = probability of perceiving a certain target identity given the presentation of that identity.
$^*p < .05$. $^{**}p < .01$.

target–nontarget similarity is low, the number of conjunction errors is barely higher than the number of feature errors. If target–nontarget similarity is high, the number of conjunction errors strongly exceeds the number of feature errors. Basically, performance in the high similarity condition was similar to the results of Experiment 5 in the sense that there was a large difference between the number of color conjunction and color feature errors. However, the difference in Experiment 6 was much larger than that in Experiment 5.

The theoretical analysis comparing the imperfect binding model with the perfect binding model revealed that the perfect binding model outperformed the imperfect binding model in the low similarity condition but not in the high similarity condition. Obviously, as already noted by Ashby et al. (1996), if the similarity among the alternative feature values is high, the all-or-none assumption will no longer be valid, possibly resulting in incorrect outcomes. However, reconstructing the model to meet the requirements set by a task in which feature similarity is relatively high (see Ashby et al., 1996, p. 187) does not result in different outcomes. More extreme, the ANOVAs on the individual parameter estimates showed that the parameters corresponding to the probabilities of perceiving the individual features were not affected by the similarity manipulation. In contrast, α estimates were dramatically affected. Moreover, the perfect binding model outperformed the imperfect binding model in the low similarity condition, whereas this was the converse in the high similarity condition. Obviously, in the low similarity condition, targets and nontargets were highly dissimilar on the basis of global features, whereas this was not the case in the high similarity condition. As a result, target–nontarget confusion errors did probably minimally occur in the former condition; in the latter condition, chances of such errors occurring were very high.

Together with the findings of Experiments 1–5, the results of Experiment 6 indicate that previous findings suggesting the existence of interdimensional illusory conjunctions might have been due to target–nontarget confusion instead of location uncertainty. Use of a paradigm such as the one used in Experiments 5 and 6 might lead to α estimates that at least partly reflect the probability of confusing the target with the nontarget. Consequently, any factor that contributes to changes in the probability of correctly discriminating the target from the nontarget may also contribute to changes in the α estimates.

General Discussion

The six experiments reported in the present article all show data patterns that are in accordance with the claim that previous findings suggesting the existence of interdimensional illusory conjunctions may have been due to target–nontarget confusion instead of imperfect binding. Experiments 1 and 2 demonstrated that when observers had to select an element on the basis of a spatial property (in the LC condition and the LO condition in Experiments 1 and 2), the number of conjunction errors never exceeded the number of feature errors. This suggests that at least accurate relative location information is available before feature information. In addition, it is striking that even in conditions with a nonspatial selection-relevant dimension, the number of conjunction errors did not exceed the number of feature errors. If the values of the selection-relevant dimension are highly discriminable, as in the case of color in Experiments 1 and 2, the number of conjunction errors generally does not exceed the number of feature errors. Obviously, if anything, an illusory conjunction account would always predict the number of conjunction errors to be larger than the number of feature errors. According to a perfect binding model, the difference between the number of conjunction and feature errors may become very small when the discrimination concerning the selection-relevant dimension is a simple one.

Experiments 1–4 showed, in addition, that maximal likelihood estimates of the probability of correct binding are generally 1 or very close to 1. Overall, the perfect binding model provided the best fit to the data. Furthermore, neither the manipulation of eccentricity nor the variation of interitem distance resulted in systematic changes in maximum-likelihood estimates of the probability of correct binding. Estimates of the probability of correctly discriminating the target from the nontarget were, however, affected by these variables. Again, these findings are opposite to the predictions of any illusory conjunction account. The fact that participants performed a primary task renders an illusory conjunction account even less likely. Concurrent primary task involvement should have created optimal conditions for illusory conjunctions to occur (Ashby et al., 1996; Treisman & Schmidt, 1982).

As mentioned before, the relevance of the conclusions in Experiments 1–4 strongly depends on the validity of the model used. The binomial model used here relies, as do the models of Ashby et al. (1996), on the feature-independence assumption. According to the feature-sampling independence assumption, the simultaneous perception of different features occurs in a statistically independent fashion. That is, perception of color identity should not be affected by orientation identity, and vice versa. As already outlined in the Method section of Experiment 1, great care was taken in the present experiment in the choice of dimension values. Furthermore, there was no evidence at all that participants were more likely to respond to one value on one dimension in dependence of the value of the other dimension. However, Experiments 1–3 suggest that participants might have been better able to perceive the orientation of the target if the target was selected on the basis of a highly salient difference in color (i.e., yellow vs. blue) relative to when this was not the case. Separate fits of models assuming a dependency between the probability of correct color discrimination and correct orientation perception revealed that α estimates were generally unaffected. Furthermore, at a behavioral level, the data patterns deviated substantially from those expected on the basis of imperfect binding. Therefore, it seems legitimate to conclude that at least the conclusions with respect to feature binding are relatively reliable.

At present, there are no studies showing that conjunction errors exclusively derive from guessing. Basically, most studies provide evidence in favor of an account similar or related to location uncertainty (Ashby et al., 1996; Cohen & Ivry, 1989; Keele et al., 1988; Prinzmetal & Keysar, 1989; Prinzmetal et al., 1986). A major reason for this discrepancy is that the demonstration that conjunction errors occur consistently more frequently than feature errors has long been considered to be indicative of the existence of illusory conjunctions (Treisman & Schmidt, 1982). Because such data patterns have typically been found, an advanced guessing account has simply not been regarded as a plausible alternative. Many authors even place the finding of more conjunction errors than feature errors on a par with the existence of illusory conjunctions. Consequently, early studies on conjunction and feature errors were restricted to the question of whether differential error rates are caused by a complete absence of preattentive location information (as originally suggested by Treisman & Schmidt, 1982) or by imperfect location information. The existence of illusory conjunctions as such was not a topic of dispute.

Only recently, several authors have suggested that illusory conjunctions may not exist (Ashby et al., 1996; Navon & Ehrlich, 1995). Thus, Ashby et al. (1996) proposed that it might theoretically be possible that observers report incorrect combinations of presented features because of guessing only. However, as outlined in the introduction, models assuming perfect binding always provided a worse fit to their data than models assuming imperfect binding. More specifically, the location uncertainty model provided the best fit to the data. Consequently, Ashby et al.'s major conclusion was that feature binding is imperfect and depends on the relative overlap of the distributions of perceived locations of the concurrently presented elements. Obviously, this view stands in strong disagreement with the present conclusion. The results of Experiment 6 show that, in a mainstream paradigm, α estimates are strongly affected by target–nontarget similarity. When a target can be discriminated from a nontarget on the basis of a highly dissimilar global feature such as height-to-width ratio, α estimates on the basis of the alpha model of Ashby et al. (1996) are generally 1 or very close to 1. Alternatively, when this is not the case, α estimates drop and may even become as low as .47, as in the high-similarity condition of Experiment 6. This suggests that previous findings indicating the existence of illusory conjunctions might have been caused by effects of target–nontarget confusion instead of imperfect binding. Indeed, as a result of the use of letter stimuli, it is even highly probable that, on some trials, target and nontarget identities were confused.

Jacobs et al. (1989) constructed several matrices expressing the confusability of alternative letters at a retinal eccentricity of 4.5° of visual angle. Inspection of the matrices shows, for example, that whereas the probability for *s* to be misperceived as *i* is very low, the probability that it is misperceived as *x* is relatively large. Thus, in peripheral vision, alternative letters differing on the basis of primitive features can still be confused (Bouma, 1971). Obviously, the generality of the values in such matrices is limited by the properties of the letters used to construct the matrices (e.g., font type and lowercase vs. uppercase) and the task on which the matrices were calculated. Yet, many studies on the perception of letters have repeatedly shown that (a) letter confusions are possible within a large range of fonts and cases (Appelman & Mayzner, 1982; Bouma, 1971), (b) the probability of letter confusion increases with increasing eccentricity (Bouma, 1971) and decreasing interitem distance (Appelman & Mayzner, 1982), and (c) the probability of letter confusion in peripheral vision is strongly related to differences in global features as opposed to local features (Bouma, 1971; Jacobs et al., 1989).

In spite of the present results, one might take the view that illusory conjunctions do exist and that these results are somehow not an accurate reflection of what is going on. To defend this point of view, one might take the position that a perfect binding account is actually rather unlikely given physiological evidence showing that vision does not include perfect location information. Indeed, there is substantial evidence suggesting that the quality of neural information concerning the absolute position of a feature is directly related to the size of the receptive fields in the visual cortex (Fiorentini, Baumgartner, Magnussen, Schiller, & Thomas, 1990; Hubel & Wiesel, 1962, 1977). Because receptive fields may cover very large areas of the visual field, it is fair to infer that location uncertainty is an inherent property of vision. However, to claim that location uncertainty leads to interdimensional illusory conjunctions is one step beyond. If an illusory conjunction is to occur, features should not only suffer from location uncertainty but actually shift positions. This implies that the existence of illusory conjunctions is conditioned on the claim that preattentive vision suffers from poor relative location information. There is not much evidence suggesting that the relative positions of alternative features of one dimension may completely reverse. Actually, several studies suggest that information concerning the relative position of one feature in relation to another is rather accurate and even necessary for complex object identification (de Valois, Lakshminarayanan, Nygaard, & Schlussel, 1990; Heathcote & Mewhort, 1993). Thus, absolute location uncertainty does not necessarily support the view that illusory conjunctions exist.

In conclusion, on the basis of the empirical evidence of Experiments 1–6, it seems legitimate to conclude that illusory conjunctions between features of different dimensions do not exist. It seems that when visual features are registered, accurate relative location information concerning these features is present as well. In the present experiments, as in the studies of many other researchers, conjunction errors were often found to be more frequent than feature errors. However, that in itself is quite expected if one considers the possibility of target–nontarget confusion.

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