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ABSTRACT

PERCEIVED QUALITY AND NUMBER OF ILLUSORILY COMBINED VISUAL FEATURES: A TEST OF FEATURE-INTEGRATION THEORY

By

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When we perceive plus-signs from displays containing only horizontal lines and vertical lines, it is generally assumed that this false perception results from the false combination of separate horizontal and vertical lines. This false perception, termed an "illusory conjunction", has been considered to be strong evidence supporting 'Feature Integration Theory' (Treisman & Schmidt, 1982). According to this theory, visual input is analyzed into separate elementary features independent of their location. These location-free visual features are combined with the help of an independent agent (i.e., focal attention). If this combination process is interrupted for some reason, visual features might be falsely combined to produce illusory conjunctions.

In this research, I examined this Feature Integration Theory explanation of illusory conjunctions. I used pre-defined target search tasks accompanied by a secondary task.

In one set of experiments, two form features (horizontal lines and vertical lines) were used in target search tasks, and the target to be searched for was a plus-sign. As a secondary task in some experiments, subjects were asked to count items in the display after checking for the presence of the target. The secondary task in other experiments was to rate their confidence in their response decision. Contrary to predictions of Feature Integration Theory, there was no reduction in the number of items perceived even when illusory conjunctions occurred, and the confidence rating of the percept based on illusory conjunctions was lower than that of the real target percept. The same data patterns were obtained when color (e.g., red) and form (e.g., horizontal lines) were used as the stimulus set. Further consideration is given to the data's implications for our understanding of the visual information processing system.

Dedicated to those who will carry out further research on this question

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CHAPTER I: INTRODUCTION

Introduction

A characteristic of many theories of visual perception is that visual input is analyzed or coded into some kind of perceptual information units (commonly called features[1]) at early stage(s) in visual information processing (Biederman, 1985; Hubel & Wiesel, 1968; Julesz & Bergen, 1983; Treisman & Gelade, 1980). These features are analyzed separately and independently of each other and are later combined to produce the percepts of coherent objects. Many psychophysical findings suggest that when, for example, we see a small white cup, features such as the color, the size, and aspects of the the form are analyzed separately (see Treisman, 1986 for a review of psychophysical findings). There also are abundant neurophysiological studies showing that some dimensions of visual features like color and movement are processed in relatively separate and localized

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Treisman (1986) discussed the possible differences between features, dimensions, and parts, and reviewed their relationships extensively. Additional consideration will be given to features and dimensions in Chapter III: Illusory Conjunctions between Dimensions, but I shall use the term 'features' to refer to features and dimensions alike.

brain areas (see Livingston & Hubel, 1988).

This analytic view of visual perception, however, leads to what has been called the "binding problem": <u>How are these separate feature codes bound together to produce veridical percepts of objects?</u> Suppose a small white cup is on a square brown table. As we know, we would not have any difficulty in perceiving it as a small white cup on a square brown table. If, however, these features are analyzed separately, why do we not perceive instead a large, square, brown cup on a small, circular, white table? How are the features correctly organized into objects?

One simple solution to the binding problem is to assume that the visual feature codes contain their own location information as part of the representation, although these feature codes are separately analyzed (cf. Crick, 1984). If these feature codes contain their own location information, we can easily imagine that these features could be correctly combined to represent veridically the original objects on the basis of their shared location. Although this assumption is intuitively acceptable and has been supported empirically as well as theoretically (e.g., Duncan & Humphreys, 1989; Keele, Cohen, Ivry, Liotti, & Yee, 1988), it has been challenged directly by other empirical evidence (e.g., Treisman & Paterson, 1984; Treisman & Schmidt, 1982) and theory (Feature Integration Theory, or FIT, by Treisman & Gelade, 1980).

For example, Treisman and her colleagues have shown that visual feature codes might be falsely combined to produce new objects under some conditions (i.e., illusory conjunctions, see below). This result has been interpreted as evidence that representations of visual features lack location information.

In this research, I focused on the relationship between representations of the visual features and their locations by examining illusory conjunctions and their explanation by FIT. As will be seen, the FIT framework used to explain illusory conjunctions could not explain the results of illusory conjunctions investigated in the current study, so several alternatives are considered in Chapter V: General Discussion.

Illusory Conjunctions and Feature Integration Theory

Treisman and her colleagues proposed one version of a feature-analytic view of visual perception (Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Sato, 1991). In this version, called 'Feature Integration Theory', features initially lack location tags. These location-free features are represented in separate feature representations, or feature maps, in which information about only one feature type is represented. These location-free features are correctly combined to form the final object percept by a linking agent called 'focal attention'. Specifically, the connection between features and their location information is established by focal attention to each location on "a master map", a representation containing the information about feature location without information about the nature of the features at those locations.

Treisman and Schmidt (1982) systematically examined one of the hidden assumptions underlying their theoretical framework: If focal attention is interrupted, features should be free-floating and might be combined falsely to produce an illusory percept of an object composed of features which are actually separated in the stimulus. For example, we might perceive a man wearing a red sweater, standing in front of a blue car when the actual stimulus is a man wearing a blue sweater, standing in front of a red car if our attention is diverted. In experimental settings Treisman and Schmidt (1982) added an auxiliary, attention-demanding task to a primary, visual search task to interrupt subjects' attention. They presented three different letters (e.g., T, N, and X) of different colors (e.g., pink, green, and brown) with a digit at each side, and asked subjects to report the two side-digits first and then to report the colored letters. Because subjects had to report two side digits first and because the display duration was short, they assumed that subjects could not deploy their focal attention to each of three letters on at least some trials. As Treisman expected, subjects sometimes reported colors and identities of different letters to belong to the same letters. They called this "an illusory conjunction," and this phenomenon has been replicated in a variety of tasks with several stimulus sets (Broadbent & Broadbent, 1986; Cohen & Ivry, 1989, 1991; Prinzmetal, 1981; Prinzmetal & Keusar, 1989; Prinzmetal, Treiman,& Rho, 1986; Treisman & Paterson, 1984; Virzi & Egeth, 1984). For example, Treisman and Paterson (1984) tested the possibility that different values of the form dimension might be falsely combined to produce illusory conjunctions[2]. They presented right angles (∟), diagonal lines (\), and, sometimes, triangles (◺). Subjects were asked to search for a triangle. Subjects sometimes reported illusory triangles from displays containing only right angles and diagonal lines.

Another study by Treisman and Gelade (1980) also supports their assumption that features initially lack location tags and are free-floating. In their Experiments 8 and 9, subjects were asked to search for and to report the identity and location of an 'orange' letter (O or X) or a pink or blue 'H' among pink O's and blue X's. In this task, subjects had to search only for the presence of a color feature ('orange'), or a form feature ('H'). The result was that even when the location report was wrong, the identity report was correct above the chance level (.678 in

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Note that illusory conjunctions between the color dimension and form dimension were examined in Treisman and Schmidt (1982). The theoretical implications about illusory conjunctions between features of the same dimension (intradimensional illusory conjunctions) and those between features of different dimensions (interdimensional illusory conjunctions) will be considered in Chapter III: Illusory Conjunctions Between Dimensions.

Experiment 8, and .748 in Experiment 9, where the chance level is .5). In contrast, the location report was roughly at chance when the target was wrongly identified. These data imply that identifying the features of visual objects might be independent of locating the features, and that feature codes lack location information.

In summary, the theoretical framework and empirical findings such as illusory conjunctions provided by Treisman and her colleagues imply that visual features are coded and analyzed separately from their locations as well as from each other. Their view distinguishes representation of feature information (which they call feature maps) from representation of location information (which they call a master map in later studies). The feature representation contains only the contents of features, while the location representation contains only the location information about discontinuities formed by objects without specifying their occupants[3].

I will call this point of view about visual features and their location information "a location-free feature code view" (or simply "location-free view"). According to this view, the binding problem is solved by assuming an

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In several papers, Treisman and her colleague also argue that there might be multiple levels of features, but the critical point is that the principle of location-free feature codes and feature-free location codes is applied to all of the levels of features (see Chapter V: General Discussion for further consideration).

integrator called 'focal attention' rather than by assuming that feature representations contain their own location information.

Some Questions about the Location-Free view

Although this location-free view is supported by the existence of illusory conjunctions and some other phenomena (see Treisman, 1986), it suffers from several weaknesses. First, do previous studies show as high an incidence of illusory conjunctions as is predicted by the location-free view? If features are truly free of location information, features should be randomly combined without serial attention and top-down constraints. Even under the situation where these are assumed (e.g., Treisman & Schmidt, 1982), however, the illusory conjunction error rate is relatively low, as though another mechanism were preventing this illusory conjunction[4].

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[4] For example, in Treisman and Schmidt's (1982) Experiment 1, three colored letters were presented between two digits. Suppose the colors were a, b, and c, and the letters were A, B, and C, and suppose for the sake of argument, there is no random noise in feature. If subjects could not examine any item with focal attention, the possible percepts are (aA, bB, and cC), (aA, bC, and cB), (bB, aC, and cA), (cC, aB, and bA), (aB, bC, and cA), and (aC, bA, and cB). In this case, the chance hit rate is about 17%, and the chance illusory conjunction error rate is 83%. If subjects managed to focus on one item, the possible percepts would be (aA, bB, and cC), (aA, bC, and cB), (aA, bB, and cC), (aC, bB, and cA), (aA, bB, and cC), and (bA, aB, and cC). In this case, the expected hit rate is 50%, and the expected illusory conjunction error rate is 50%. The estimated conjunction error rate in either case is higher than the obtained conjunction error rate (39%).

Second, it is unclear how focal attention on a master map can restore the contents of features at each location if the master map does not specify "which features or dimensions create the discontinuities" (Treisman, 1990, p460; see Navon, 1990a, 1990b; Treisman, 1990 for similar arguments). Further, if information about the content of each location is accessible only through serial focal attention, how can we, though incorrectly, locate features when serial focal attention is not allowed? In other words, it is unclear why features are falsely combined rather than simply remaining unconjoined (Johnston & Pashler, 1990).

Third, several studies imply that features are contingent on their location codes. For example, Johnston and Pashler (1990) pointed out two problems in Treisman and Gelade (1980). The first one is the 'negative-information problem'. If subjects could identify one type of target more easily and more frequently than the other type of target, and if they suspect that two types of target occur equally often, they might guess that in trials in which no targets were detected, the actual target is more likely to be the other type of target. This negative inference strategy will allow subjects to guess at better than chance levels. In other words, with only this strategy they could report the identities of targets with higher than chance accuracy even when the location report is at chance.

The second problem is the 'location-information problem'. In Treisman and Gelade (1980), displays contained two rows of six letters each, and targets could appear at one of the middle four locations. Therefore, it is possible that subjects sometimes correctly coded both the identity of the target and its location in internal coordinates, but they failed to translate those coordinates into a stimulus position because there were no usable landmarks.

To control the negative-information problem, Johnston and Pashler (1990) equalized the difficulty of the two features and allowed subjects to make a "nontarget" response rather than forcing an identity guess. To control the location-reporting problem, they used a geometric arrangement of stimulus locations and masking fields that could provide strong anchoring of target locations. With these problems controlled, Johnston & Pashler (1990) examined Treisman and Gelade (1980) and found that feature identity was almost at chance level when the location was unknown, unlike Treisman and Gelade (1980). This result implies that form features are contingent on the location information.

Similarly, Nissen (1985) showed that color processing and form processing depends on location processing but are relatively independent of each other (cf. Monheit & Johnston, 1994). Nissen therefore proposed that shared locations might be the basis of cross-referencing between separate dimensions, such as color and shape.

These data suggest that some representation containing features contingent on their location should be assumed in visual processing.

Experimental Logic

In this research, I tried to examine the location-free view of feature codes by using two elaborations of a standard illusory conjunction paradigm (Prinzmetal, 1981). These elaborations were designed to answer two questions. The first question is: <u>Do features producing an illusory conjunction leave traces at their original locations?</u> In other words, once features are combined to produce an illusory conjunction at another location, do they leave traces at their initial locations? According to the location-free view, illusory conjunctions result from the false combinations of features lacking location information. Thus, features will not leave any trace after they are illusorily combined with other features[5].

The other question is whether the percept resulting from an illusory conjunction is different from a veridical percept. That is, <u>is the percept from an illusory conjunction indistinguishable from the percept resulting from correct feature integration?</u> The location-free view predicts no difference in the two kinds of percepts because the visual system contains no information to differentiate

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Interestingly Treisman and Schmidt (1982) also agreed that there might be traces (they called them ghosts) after visual features were illusorily combined with other features, which seems inconsistent with their theoretical framework.

the real percept from the illusory conjunction based percept.

In this study, these two questions were asked using auxiliary counting and confidence rating tasks along with a conventional visual search task.

Counting Task

According to the location-free view, illusory conjunctions result from the false combination of separate features. This view predicts that the item that initially possessed a feature now used in an illusory conjunction no longer possesses that feature. To test this prediction, I used items consisting of only one distinguishing feature[6], and I asked subjects to count the items presented in the display after searching for the presence of the target[7].

In Prinzmetal's task (1981), for example, horizontal lines, vertical lines, and/or a plus-sign made of an intersecting horizontal and vertical line are presented, and subjects are asked to search for a plus-sign in the display.

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Of course, any visual stimulus might contain multiple features. For example, a horizontal line, like that used in Prinzmetal (1981) and in the current study, contains many visual features, such as length, width, color, and orientation. By only one distinguishing feature I mean that the stimulus contains only one feature that can distinguish the stimulus from other stimuli and is relevant to task performance.

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If items contain two or more features, subjects could count items correctly, relying on the remaining features at the initial locations, and we could not examine the predictions of the location-free view.

If subjects perceive a plus sign in displays containing horizontal lines and one vertical line but no plus-sign, this illusory conjunction might be explained by assuming that one of the horizontal lines and one vertical line were falsely combined. Most relevant to my interest, when asked to count items in the display, the location-free view predicts that subjects will perceive one fewer item because two of the items (one horizontal line and one vertical line) have been combined into one (a plus sign).

Confidence Rating Task

The second auxiliary task requires subjects to rate their confidence in their response. That is, subjects are asked to rate their confidence in their response about the presence of the target after reporting their presence/absence judgement. The comparisons of interest are of the confidence rating on trials where an illusory conjunction is perceived relative to the confidence rating when a real target is correctly perceived. The location-free view predicts that the confidence ratings for the real target and illusory conjunctions should not differ because the perceptual system does not distinguish the real plus percept from the false percept of a plus in the illusory conjunction condition.

CHAPTER II: COUNTING AND CONFIDENCE RATING IN ILLUSORY CONJUNCTIONS WITHIN DIMENSION

I carried out 5 experiments with this logic. In Experiments 1a and 1b, I added a counting task to a conventional illusory conjunction task. In Experiment 2a, 2b, and 2c, I replaced the counting task with a confidence rating task.

Experiments 1a and 1b

In these experiments, I adopted Prinzmetal's task (1981) as the basic illusory conjunction task, and included a counting task as a secondary task.

In Experiment 1a, I presented combinations of three to five horizontal lines, vertical lines, or plus signs on each trial. Subjects were asked to search for a plus sign among distractors that were either horizontal or vertical line segments. Some trials included distractors of only one type; others included both types.

After reporting whether a plus-sign was present, subjects were asked to count the items in the display. As mentioned earlier, the location-free view predicted that the number of items perceived would be reduced when an illusory conjunction was perceived if the illusory conjunction (i.e., a plus-sign) resulted from the false combination of two separate features (i.e., a vertical line and a horizontal line).

In Experiment 1a, I also examined an alternative explanation of illusory conjunctions based on response bias. According to this explanation, illusory conjunctions are just an epiphenomenon, not a perceived event, and there is no false combination of features to produce illusory conjunctions. Specifically, subjects might be biased to report a target whenever the items in the display are unclear, and some critical or salient features of targets (e.g., horizontal lines and vertical lines in Experiment 1a) are identified (cf. Duncan & Humphreys, 1989). Because the illusory conjunctions are inferred from the difference between false-alarm rates of displays containing all[8] components of the target (both horizontal lines and vertical lines in this experiment) and displays containing only some components of the target (only horizontal lines or only vertical lines in this experiment)[9], the adoption of this

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Although Treisman and Paterson (1984) examined and confirmed the role of the emergent features resulting from the combination of form features (e.g., the occurrence of an intersection in a plus-sign resulting from the combination between a horizontal line and a vertical line), they still showed that form features lacking the emergent feature were sufficient to produce illusory conjunctions.

9

For the logic underlying this estimation of illusory conjunctions see Treisman and Schmidt (1982) or the results strategy would produce a significant number of illusory conjunctions. To test this explanation, I manipulated the probability that the target was present in the display. I assumed that the higher expectation of the target presence would increase the subject's likelihood of adopting this strategy.

In Experiment 1b, I sometimes included an 'x' in displays to induce subjects to experience more illusory conjunctions by adding another feature of a plus-sign, 'intersection' (Treisman & Paterson, 1984). As in Experiment 1a, subjects were asked to search for the plus-sign, and then to count the items present in the display.

Method

Subjects

Thirty nine and 21 students participated in Experiments 1a and 1b, respectively, as part of their course activities in Introductory Psychology Classes at Michigan State University. In Experiment 1a, 13 subjects were assigned to each of three between-subject groups (high target probability, high feature probability, and high conjunction probability, described below in detail).

There was no between-subject variable in Experiment 1b, and the data of one of 21 subjects were excluded because of a misunderstanding of the instructions.

All subjects reported normal color vision and were

(continued from the previous footnote)
and discussion section of this experiment.

naive about the exact purpose of the experiments.

Apparatus

The students were individually tested in a dimly lit room. Stimuli were presented on a noninterlaced multisynch Nec-4D high resolution 15" color monitor in Experiment 1a. The monitor was driven by an Orchid SVGA graphics card (Prodesigner IIe), which refreshed the screen at a rate of 72 Hz and was controlled by a 386-25 MHz Compuadd computer.

In Experiment 1b I also used another computer system, the monitor of which was a Seiko CM-1450 high resolution 13" color monitor driven by an Orchid SVGA graphics card (Prodesigner IIe), controlled by a 386SX-20 MHz Compuadd computer. To equalize the stimulus size on the two different monitors, I used the horizontal and vertical size controls of the monitors.

All stimuli were drawn in a VGA-MED graphics mode (640 x 350 resolution). Successive displays were drawn on separate graphics pages, and page changes were synchronized to the raster retrace. The distance of the subjects from the monitor screen was not controlled but was approximately 70cm.

Stimuli

As in Prinzmetal (1981), vertical lines, horizontal lines, and plus-signs formed from vertical lines and horizontal lines were used as stimuli. The stimuli were distributed among nine circles (location markers). These circles were aligned in a three by three square as "placeholders" to prevent subjects from using a counting strategy based on very minimal information from the filled locations (Treisman & Gormican, 1987). The angular size of a circle was approximately .79 degree (.96cm) in diameter, and the gap size between nearby circles was .26 degree (.32cm), which is the same size as the within-gap-size of Experiment 1 in Prinzmetal (1981). The circles were drawn in light-blue. Vertical lines were drawn in white, but horizontal lines were drawn in light gray in order to achieve a match of the horizontal lines and vertical lines in apparent brightness on the monitors.

In Experiment 1a, the number of target stimuli presented on each trial was varied randomly between 3 and 5 items from trial to trial. In the case of 3-item trials, two horizontal lines (horizontal line fillers) or two vertical lines (vertical line fillers) were presented in any two circles, and the remaining item could be a plus-sign ('target present' or 'target' condition), the same line as the fillers ('feature' condition), or the line different from the fillers ('conjunction' condition). It was the same in 4-item trials and 5-item trials except for the addition of 1 or 2 fillers. In other words, on every trial the other items except for one critical item were homogeneously horizontal lines or vertical lines. The ratio of horizontal line fillers and vertical line fillers across trials was 50:50, and the number of items (3, 4, and 5) was also equalized. The filler type and the number of items were randomly distributed over trials, and the locations where items were presented were also randomized across the nine possible circles.

In Experiment 1b, an 'x' was presented on half of the trials in an attempt to induce subjects to perceive more illusory conjunctions by adding the feature of intersection (Treisman & Paterson, 1984). In the display containing an 'x', one of the fillers was dropped to equate the number of items in displays without an 'x'. This presence or absence of an 'x' was manipulated within blocks. The composition of the total stimulus set is summarized in Table 1, and the examples of target displays are drawn in Figure 1.

Differently from Prinzmetal (1981), where stimuli were drawn in black on a white background and a regular pattern of small black dots was used for pre- and post-masks, I used white stimuli on a black background and a white dot screen for masks in Experiment 1a, and pattern masks containing parts of horizontal lines, vertical lines, and x's in Experiment 1b (see Figure 2)[10]. The mask size was 7.86 x 7.86 degrees (9.6 cm x 9.6 cm), which covered the area of the target and location markers (i.e., nine circles).

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In Experiment 1b, I sometimes included an 'x' in the display, which contained another feature of the target plus-sign (i.e., intersection), to induce subjects to experience more illusory conjunctions (see Treisman & Paterson, 1984). During pilot experiments, I found that this 'x' was salient enough to escape the masking effect of premasks and postmasks, so I changed the pre- and postmasks from dot masks to pattern masks containing fragments of x's, as well as fragments of horizontal lines, and vertical lines.

Table 1. The Composition of the Stimulus Set.

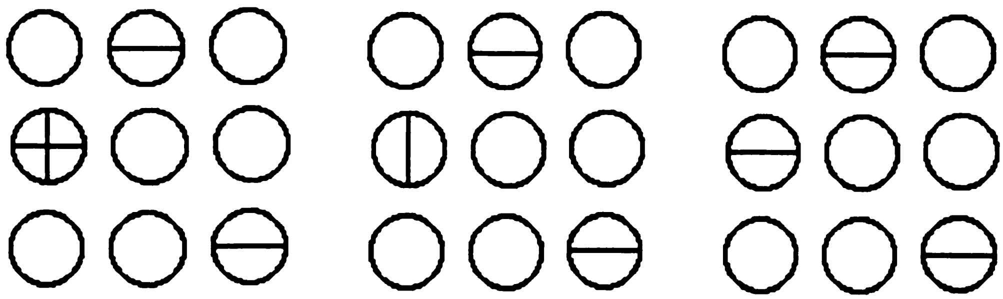
	Plus	Feature	Conjunction
Experiments 1a, 2a, (2b)			
Three items			
horizontal	PHH(X)*	HHH(X)	VHH(X)
vertical	PVV(X)	VVV(X)	HVV(X)
Four items			
horizontal	PHHH(X)	HHHH(X)	VHHH(X)
vertical	PVVV(X)	VVVV(X)	HVVV(X)
Five items			
horizontal	PHHHH(X)	HHHHH(X)	VHHHH(X)
vertical	PVVVV(X)	VVVVV(X)	HVVVV(X)
Experiments 1b, 2c			
X-present displays			
Three items			
horizontal	PHX	HHX	VHX
vertical	PVX	VVX	HVX
Four items			
horizontal	PHHX	HHHX	VHHX
vertical	PVVX	VVVX	HVVX
Five items			
horizontal	PHHHX	HHHHX	VHHHX
vertical	PVVVX	VVVVX	HVVVX
X-absent displays			
Three items			
horizontal	PHH	HHH	VHH
vertical	PVV	VVV	HVV
Four items			
horizontal	PHHH	HHHH	VHHH
vertical	PVVV	VVVV	HVVV
Five items			
horizontal	PHHHH	HHHHH	VHHHH
vertical	PVVVV	VVVVV	HVVVV
Experiments 3, 4			
Three items			
horizontal	THH	HHH	CHH
vertical	TCC	CCC	HCC
Four items			
horizontal	THHH	HHHH	CHHH
vertical	TCCC	CCCC	HCCC
Five items			
horizontal	THHHH	HHHHH	CHHHH
vertical	TCCCC	CCCCC	HCCCC

Abbreviations P=plus sign; H= white horizontal line; V=vertical line; C=red circle; T=red horizontal line.

* In the displays of Experiment 2b, an extra 'x' was added to the displays of Experiment 2a.

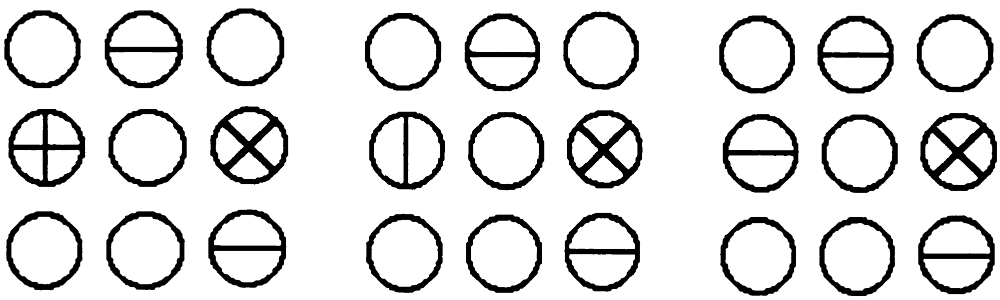
(a) Displays of Experiments 1a, 2a, no-x displays of Experiments 1b and 2c

Target displays Conjunction displays Feature displays



(b) X-displays of Experiments 1b, 2b, and 2c

Target displays Conjunction displays Feature displays



(c) Displays of Experiments 3a and 3b

Target displays Conjunction displays Feature displays

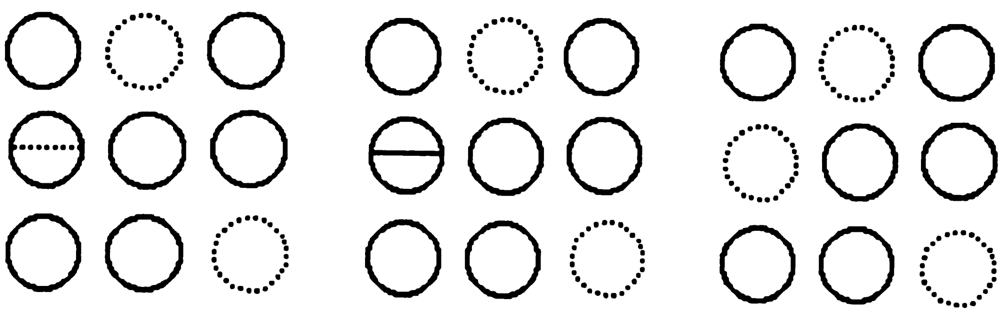
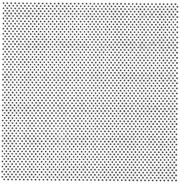
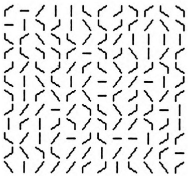


Figure 1. Examples of stimulus displays used in this research (dotted circles and a dotted line in (c) represent red color, whereas the solid circles and lines represent white color).

(a) a dot-mask used in Experiment 1a and 2a



(b) a pattern-mask used in Experiments 1b, 2b, and 2c



(c) a color-mask used in Experiments 3 and 4 ('▭' represents white color, and '⬚' represents red color.)

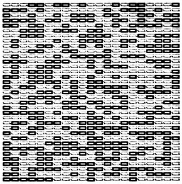


Figure 2. Examples of dot-masks and pattern-masks used in this research.

<u>Procedure</u>

Each trial consisted of three events. First, a white dot mask or a pattern mask was presented, centered on the screen, accompanied by a 2000 Hz warning tone for 520 msec. This premask was replaced by the stimulus display containing 9 circles (i.e., place holders) and 3, 4, or 5 stimuli, depending on the display conditions. The duration of the stimulus display was varied over trials, based on the average error rate (see below) to ensure that subjects made some errors. After that, the same white dot mask or pattern mask replaced the stimulus display without any warning sound. This post-mask remained visible until the subjects responded.

Subjects had to report first whether or not the stimulus display contained a plus-sign, by pressing '/' or 'z' on the computer keyboard. They then were asked to report the total number of items in the display, not including the circles, by pressing the '3', '4', or '5' key.

Experiment 1a was divided into 4 stages. The first stage was an instruction stage, in which subjects were presented with instructions and some examples. The second stage was a threshold stage, where the duration of the stimulus display that produced the desired error rate was approximated. The third stage was the main data-collection stage, which consisted of 5 blocks of 96 trials each. Finally, in the feedback stage, an experimenter summarized the data for the subjects and explained the purpose of the experiment.

The duration of the stimulus display in the threshold stage in Experiment 1a was controlled as follows. The initial presentation time was 8 frames (112 msec). After every ten trials, the duration was reduced by 2 frames if there were no errors, or 1 frame if there was 1 error. It was increased by 1 frame in the case of 3 or 4 errors or by 2 frames in the case of 5 or more errors. This threshold-setting stage ended if, in two successive blocks of ten trials, there were two or more errors, or if the total number of trials in the threshold stage exceeded 40 trials[11]. The final duration obtained was used as the starting duration of the first main block. This duration-control-strategy was slightly modified in the main stage to keep the duration more stable. If one error or no errors were made in 10 trials, the duration was reduced by 1 frame, and if 4 or more errors were made in 10 trials, the duration was increased by 1 frame. Otherwise the duration did not change. The duration of the last trial of each block was used as the starting duration of the next block.

In Experiment 1b, I dropped the threshold setting

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From pilot experiments, I found that it was very hard to decide the appropriate duration of target displays to produce some errors, and that it sometimes took more than 30 minutes. Therefore, we adopted a pseudo-threshold setting rule described in Experiment 1a. In Experiment 1b, I changed some aspects of the tasks including masks to increase the difficulty of the target searching tasks, and I used a different rule to set threshold.

stage. Instead, I started the duration at 9 frames and applied the duration-control rule used in Experiment 1a to the 'x'-condition and 'no x'-condition separately, because a pilot study showed the average duration required to attain the criterion error rate was shorter in the 'no x' condition than in the 'x' condition. There were 6 blocks, which, in turn, contained 60 trials. The first block was considered to be a practice block, and this was not analyzed.

The stimulus duration averaged about 28 to 34 msec in Experiment 1a, 169 to 238 msec in displays containing an 'x' in Experiment 1b, and 118 to 196 msec in displays containing no 'x' in Experiment 1b. Block by block means are shown in Table 2.

All the instructions for these experiments, including some sample displays, were presented on the screen and subjects could proceed self-paced in this instruction phase by pressing a key to advance screens. The total experimental session took subjects approximately 50 minutes.

To test the response bias explanation of illusory conjunctions in Experiment 1a, I used a different proportion of target present trials across subjects. There were three groups (high target display, high conjunction display, and high feature display). In each group, one type of display occurred on 50 percent of the trials with the remaining two types each occurring on 25 percent of the trials. Therefore, 50 percent of the trials in the high target display group were target-present displays, and the feature displays and

Table 2. Block-by-block Means (SD) of Stimulus Display Durations in This Study (msec)

Experiments	Block 1	Block 2	Block 3	Block 4	Block 5
Exp 1a	29 (18)	31 (23)	34 (26)	33 (25)	33 (27)
Exp 1b with 'x'	238 (25)	208 (41)	188 (48)	178 (57)	170 (63)
Exp 1b w/o 'x'	196 (36)	152 (42)	126 (40)	119 (41)	120 (46)
Exp 2a	32 (8)	32 (11)	37 (19)	39 (26)	48 (42)
Exp 2b	37 (11)	46 (23)	52 (32)	54 (34)	54 (42)
Exp 2c with 'x'	218 (32)	186 (41)	160 (48)	155 (53)	158 (55)
Exp 2c w/o 'x'	188 (25)	138 (30)	114 (23)	108 (27)	110 (29)
Exp 3	194 (44)	147 (50)	142 (49)	147 (56)	168 (72)
Exp 4	183 (56)	132 (38)	130 (50)	132 (40)	131 (38)

conjunction displays each occurred on 25 percent of the trials. Likewise, the high feature display group and high conjunction display group contained 50 percent of the feature display trials or conjunction display trials, and the other two types of displays each occurred on 25 percent of the trials.

Design

The design of Experiment 1a was mixed, having within-subject comparisons of Display Type ('feature', 'conjunction', and 'target') x Numbers of Items (3, 4, and 5 items) x Filler Type (horizontal or vertical fillers), and the between-subject variable was the target presence probability (high target display, high feature display, and high conjunction display). There was no between-subject variable in Experiment 1b. Instead, another within-subject variable ('x' or no 'x') was manipulated.

Results

In Experiment 1a, there was no main effect of the probability manipulation, $F(2,36)=.554$, $p > .5$ overall, and, more importantly, no interaction with display type. In other words, the variation in the probability of the target presence did not influence the occurrence of illusory conjunctions in Experiment 1a (estimated amount of illusory conjunctions: 7.2% in high target display; 5.8% in high conjunction display; 9.0% in high feature display), $F(2,36)=.608$, $p > .5$, which is inconsistent with the response bias-based explanation of illusory conjunctions. In the following analyses, I collapsed the data across the probability manipulation.

The miss ('no' responses for target displays) and false-alarm ('yes' responses for feature displays or conjunction displays) rates are shown in Table 3. I analyzed the data in two steps to determine first whether illusory conjunctions were obtained in this task, and then whether the counting error pattern depends on the display type.

Illusory Conjunction Phenomenon

Experiment 1a.

I compared the data from feature displays with those from conjunction displays because in feature displays containing only horizontal lines or only vertical lines, the perception of a plus caused by mislocalization cannot occur. Thus, the false alarm rate of feature displays could be used as a baseline for examining illusory conjunctions (Treisman & Schmidt, 1982).

A three-way ANOVA was conducted on the false-alarm rates (%) of the feature and conjunction conditions. In this analysis, two levels of Display (feature and conjunction), three levels of Item Number (three, four, and five), and two levels of Fillers (horizontal and vertical fillers) were within-subject variables.

The main display-type effect was highly significant, $F(1,36)=37.577$, $p < .001$ (M=11.1% in feature and 18.4% in conjunction displays). The estimated illusory conjunction rate of 7.3% was obtained by subtracting the false alarm

Table 3. Average Error Rates(%) in Target Displays, Feature Displays, and Conjunction Displays (Experiment 1a, 1b).

Display Type	Number of Items			average
	three	four	five	
(Experiment 1a)				
Miss in Target	6.1	6.0	7.3	6.5
FA in Feature	10.8	10.7	11.7	11.1
FA in Conjunction	16.5	18.2	20.4	18.4
means of FAs	13.7	15.0	16.1	
estimated IC rate	5.7	7.5	8.7	7.3
(Experiment 1b)				
X-present Displays				
Miss in Target	10.3	11.0	14.5	11.9
FA in Feature	14.5	18.0	16.0	16.2
FA in Conjunction	26.3	29.8	31.5	29.2
means of FAs	20.4	23.9	23.8	
estimated IC	11.8	11.8	15.5	13.0
X-absent Displays				
Miss in Target	18.0	18.0	22.3	19.4
FA in Feature	11.8	14.8	14.0	13.5
FA in Conjunction	20.5	23.5	32.0	25.3
means of FAs	16.2	19.2	23.0	
estimated IC	8.7	8.7	18.0	11.8

Abbreviations FA = false-alarm responses in feature displays and conjunction displays; Miss = miss responses in target displays; IC = illusory conjunction. The estimated IC rate was computed by subtracting FA in feature displays from FA in conjunction displays.

rate of feature displays from that of conjunction displays. The main Item Number effect was also significant; $F(2,72)=3.707, p < .05$ (M=13.7% with three items, 15.0% with four items, and 16.1% with five items). But there was no main effect of Filler, $F(1,36)=.242$, $p > .6$ (M=14.9% with horizontal and 14.5% with vertical fillers). There were no significant interactions between the variables; for all interactions, $p > .1$.

As expected from the earlier studies of illusory conjunctions (e.g., Prinzmetal, 1981; Treisman & Paterson, 1984), the false-alarm rate in the conjunction condition was higher than that of the feature condition. This implies that there are illusory conjunctions in the conjunction condition (7.3% estimated illusory conjunctions). The main effect of Number of Items reflects the fact that the more items presented, the higher the false alarm rate, but the lack of an interaction between number of items and display type means that there is no increase in the estimated number of illusory conjunctions.

Experiment 1b.

As in Experiment 1a, a four-way ANOVA was conducted on the false-alarm rates (%) of the feature and conjunction conditions. In this analysis, two levels of Display (feature and conjunction), three levels of Item Number (three, four, and five), two levels of Fillers (horizontal and vertical fillers), and the presence of an 'x' were within-subject variables.

The main display-type effect was highly significant, $F(1, 19)=60.097$, $p < .001$ (M=14.9% in feature and 27.3% in conjunction displays). The main Item Number effect was also significant; $F(2,38)=6.219$, $p < .01$ (M=18.3% with three items, 21.5% with four items, and 23.4% with five items). The presence of an 'x' affected the error rate significantly, $F(1, 19)=4.677$, $p < .05$ (M=19.4% in the x-display, and 22.7% in the no x-display), but there was no main Filler effect, $F(1, 19)=1.871$, $p > .1$. Among the interactions between the variables, only the interaction between Display and Item Number was significant, $F(2,38)=3.569$, $p < .05$ (M=10.3% difference with three items, 10.3% difference with four items, and 16.8% difference with five items), and the other interactions were all $p > .2$.

Again the false-alarm rate in the conjunction condition was higher than that of the feature condition, which implies that there were illusory conjunctions in the conjunction condition. The estimated amount of illusory conjunctions was 11.8% in displays with an 'x', and 13.0% in displays without an 'x'. The main effect of Number of Items implies that the more items presented, the higher the false alarm rate. Unlike in Experiment 1a, the interaction between number of items and displays was significant, which means that the estimated number of illusory conjunctions increased as the number of items increased, mostly from four to five items.

Finally, the significant effect of the presence of an 'x' was in the direction opposite to that expected. That is, the false alarm rates of feature displays and conjunction displays were lower when an 'x' was included (19.4% on average) than when there was no 'x' (22.7% on average). The inclusion of an 'x' increased the miss rate in target displays, and the interaction between the three display types and the presence of an 'x' was significant, $F(2,38)=10.399$, $p < .001$, which was attributable to the higher misses and lower false-alarms in x-displays, and vice versa in no-x-displays. It is unclear why the presence of an 'x', which has one of the critical features of plus-signs, increased the miss rate and decreased the false-alarm rates. It might be that subjects have misattributed the intersection of a plus-sign , whether it was a real plus-sign or not, to the 'x', because of the saliency of the intersection of the 'x'.

Counting Responses

Next, I analyzed the change in counting response patterns as a function of the occurrence of illusory conjunctions. In this analysis, I used only data from subjects who showed more conjunction false-alarms than feature false-alarms, because the occurrence of illusory conjunctions was prerequisite to examining the location-free view.

Two steps were required to calculate the counting response patterns of conjunction false-alarms predicted by the two views. The first step was to decompose false-alarm responses in the conjunction condition into a proportion due to illusory conjunctions and a proportion due to random-errors, because the conjunction false-alarms could result both from the false combination of features and from random noise (Treisman & Schmidt, 1982). I calculated the contributions of each part by the formula,

$$IC_{prop} = (Conjunction_{error} - Feature_{error})/Conjunction_{error},$$

$$Random_{prop} = Feature_{error}/Conjunction_{error},$$

where IC_{prop} and $Random_{prop}$ are the proportions of illusory conjunctions and random-errors in conjunction false alarms, $Conjunction_{error}$ and $Feature_{error}$ are the conjunction and feature false-alarm rates.

The next step was to compute the counting response patterns of the illusory conjunction portion and of the random noise portion, predicted by the location-free view, and finally to combine them by computing a weighted average of the two counting patterns, weighing each by the proportion calculated as shown above. The predicted counting response pattern of conjunction false-alarm responses ($Counting_{predicted}$) is calculated with the following formula,

$$Counting_{predicted} = (IC_{prop} * Counting_{ic}) + (Random_{prop} * Counting_{random}),$$

where $Counting_{predicted}$ is the counting response pattern predicted by the location-free view, $Counting_{ic}$ is counting response pattern obtained in the illusory conjunction portion of the conjunction condition, and Counting_{random} is the counting response pattern of the random error portion of the conjunction condition.

To calculate the counting response patterns of the illusory conjunction portion and the random error portion, I relied on the location-free view's implicit assumptions about the feature representation. According to the location-free view, the final percept of the illusorily formed target percept is not distinguishable from the correct target percept, and the number of items perceived is reduced by one in illusory conjunctions, because two parts have been conjoined to form one. Thus I used the counting response pattern of hits in 4-item target displays to estimate the counting response pattern of the illusory conjunction portion in 5-item conjunction displays, and I used the counting response pattern of false-alarms in 5-item feature displays for the counting response pattern of the random error portion in 5-item conjunction displays.

The same logic was applied to the case of 4-item conjunction displays. I used the counting response patterns of hits in 3-item target displays and of false-alarms in 4-item feature displays for the counting response patterns of the illusory conjunction portion and random error portion in the 4-item conjunction displays. In the case of 3-item conjunction displays, I could not estimate the counting response pattern, because there were no 2-item target displays to estimate the counting response patterns expected if two items (one target and one distractor) were presented. This logic is depicted in Figure 3a. Formulae used to estimate counting response patterns of false-alarms in conjunction displays, predicted by the location-free view can be summarized as follows:

$$\text{Counting}_{\text{predicted}(5)} = (\text{Counting}_{\text{hit}(4)} * \text{IC}_{\text{prop}}) + (\text{Counting}_{\text{feature}(5)} * \text{Random}_{\text{prop}}),$$

$$\text{Counting}_{\text{predicted}(4)} = (\text{Counting}_{\text{hit}(3)} * \text{IC}_{\text{prop}}) + (\text{Counting}_{\text{feature}(4)} * \text{Random}_{\text{prop}}),$$

where $\text{Counting}_{\text{predicted}(5)}$ and $\text{Counting}_{\text{predicted}(4)}$ are the counting responses patterns of 5-item and 4-item conjunction displays predicted by the location-free view, $\text{Counting}_{\text{hit}(4)}$ and $\text{Counting}_{\text{hit}(3)}$ are counting response patterns of hit responses obtained in 4- and 3-item displays, and $\text{Counting}_{\text{feature}(5)}$ and $\text{Counting}_{\text{feature}(4)}$ are counting response patterns of false-alarms obtained in 5- and 4-item displays[12].

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I also calculated the counting response patterns expected if there was no reduction in the number of items when illusory conjunctions were experienced. I used the counting response pattern of hits in five item target displays and that of false-alarms in five item feature displays to estimate the counting response pattern of false-alarms in five item conjunction displays. Likewise I used the counting response pattern of hits in four item target displays and that of false-alarms in four item feature displays to estimate the counting response pattern of false-alarms in four item conjunction displays. This logic is shown in Figure 3b.

Experiment 1a.

The obtained, and predicted counting response patterns for the 29 of 39 subjects who showed illusory conjunctions[13] in Experiment 1a are shown in Table 4, Figure 4, and Figure 5. As can be seen, the conjunction false-alarm counting response pattern predicted by the location-free view was different from the obtained conjunction false-alarm counting response pattern. Specifically, the estimated ratios of counting three and counting four items in 4-item displays were 59.4% and 32.7%, which were outside of the 95% confidence intervals (7.9% - 19.1% for counting three items; 67.1% - 82.1% for counting four items). The difference between the counting response pattern predicted by the location-free view and the obtained counting response pattern was also observed in five item displays (predicted value: 8.9% vs. 95% confidence interval of the obtained value: 0.6% - 4.2% in counting three from 5-item displays; predicted value: 67.2 vs. 95% confidence interval of the obtained value: 23.6 - 42.6 in counting four from 5-item displays; predicted value: 23.9 vs. 95% confidence interval of the obtained value: 54.2 - 74.8 in counting five from 5-item displays).

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Either because of random variation or individual differences, only 29 of 39 subjects made illusory conjunction errors. Because the location-free view predicts a reduction in the number of items perceived only when illusory conjunctions occur, the analysis of the counting responses was restricted to those subjects for whom the estimated rate of illusory conjunctions was positive.

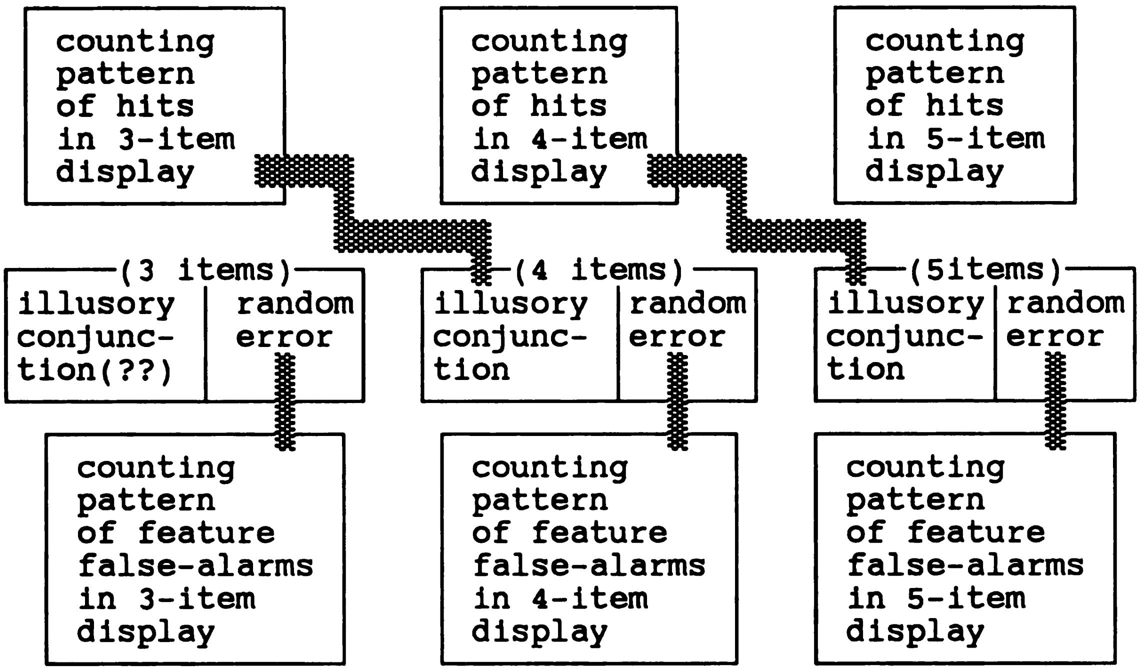

Figure 3a. The estimation of the counting response patterns of false-alarm responses in conjunction displays predicted by the location-free view.

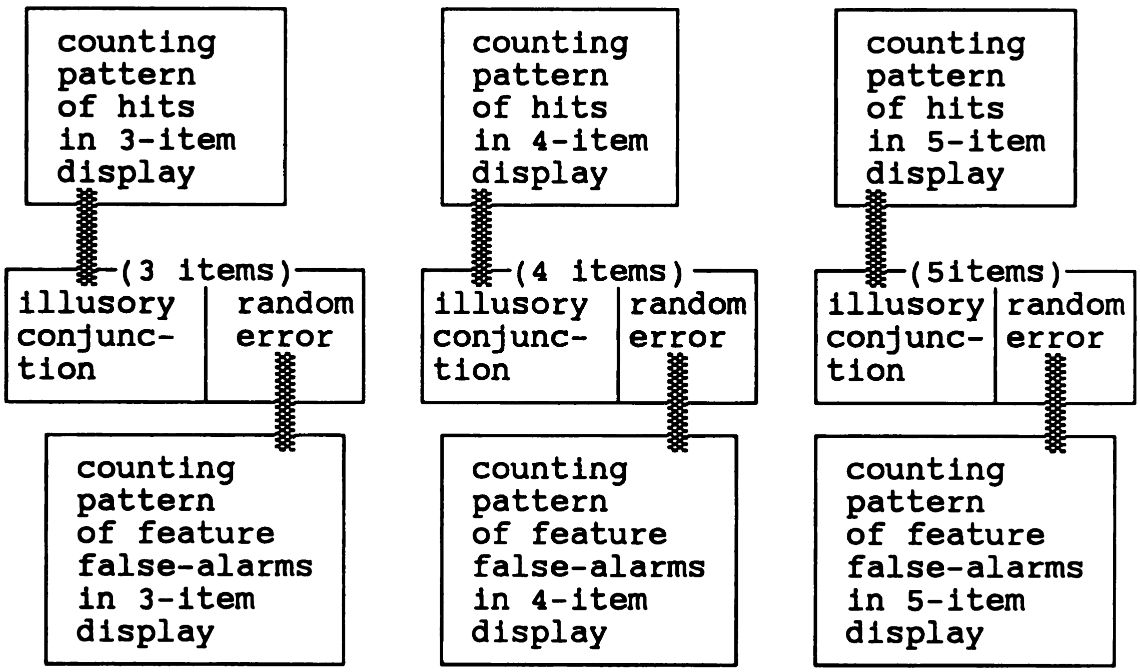

Figure 3b. The counting response patterns expected if there was no reduction in the number of items perceived when illusory conjunctions were experienced.

Table 4. 95% Confidence Interval of Obtained Conjunction False-Alarm Counting Response Patterns, and the Prediction of the Location-Free View in Experiment 1a.

stimuli	Counting Responses		
	3 items	4 items	5 items
4 items			
obtained data			
obtained	13.5	74.6	11.9
upper-limit	19.1	82.1	17.0
lower-limit	7.9	67.1	6.8
predicted data			
location-free	59.4*	32.7*	7.9
control+	9.8	77.9	12.3
5 items			
obtained data			
obtained	2.4	33.1	64.5
upper-limit	4.2	42.6	74.8
lower-limit	0.6	23.6	54.2
predicted data			
location-free	8.9*	67.2*	23.9*
control	4.1	30.6	65.2

Note This analysis was based on the data from the subjects who showed positive illusory conjunctions (29 subjects).
* These data deviate from the 95% confidence interval of the obtained data.
+ This control indicates the counting response patterns expected if there was no reduction in the number of items perceived when illusory conjunctions occurred.

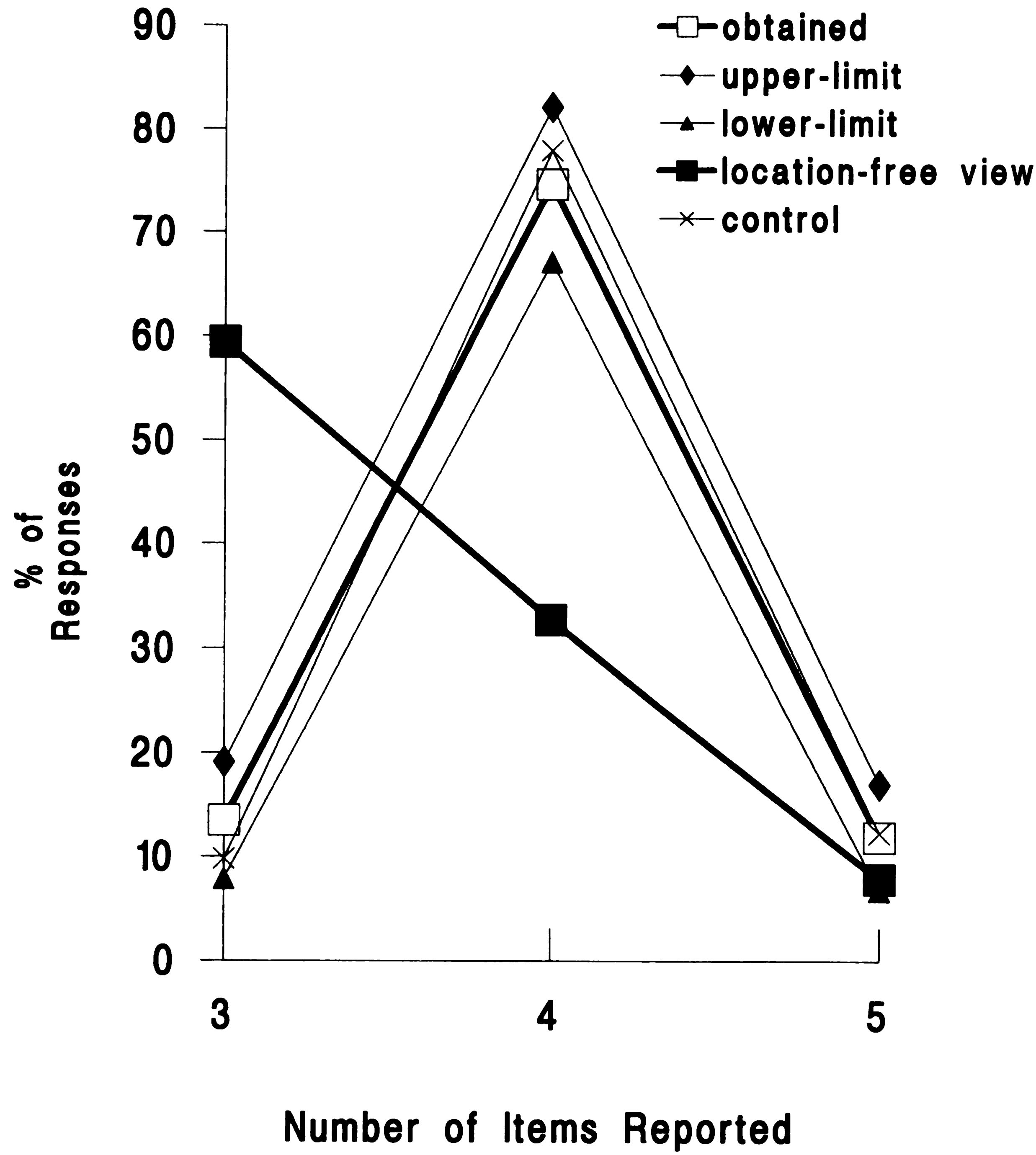

Figure 4. 95% confidence interval around obtained conjunction false-alarm responses, and the prediction by the location-free view (4 items in Experiment 1a).

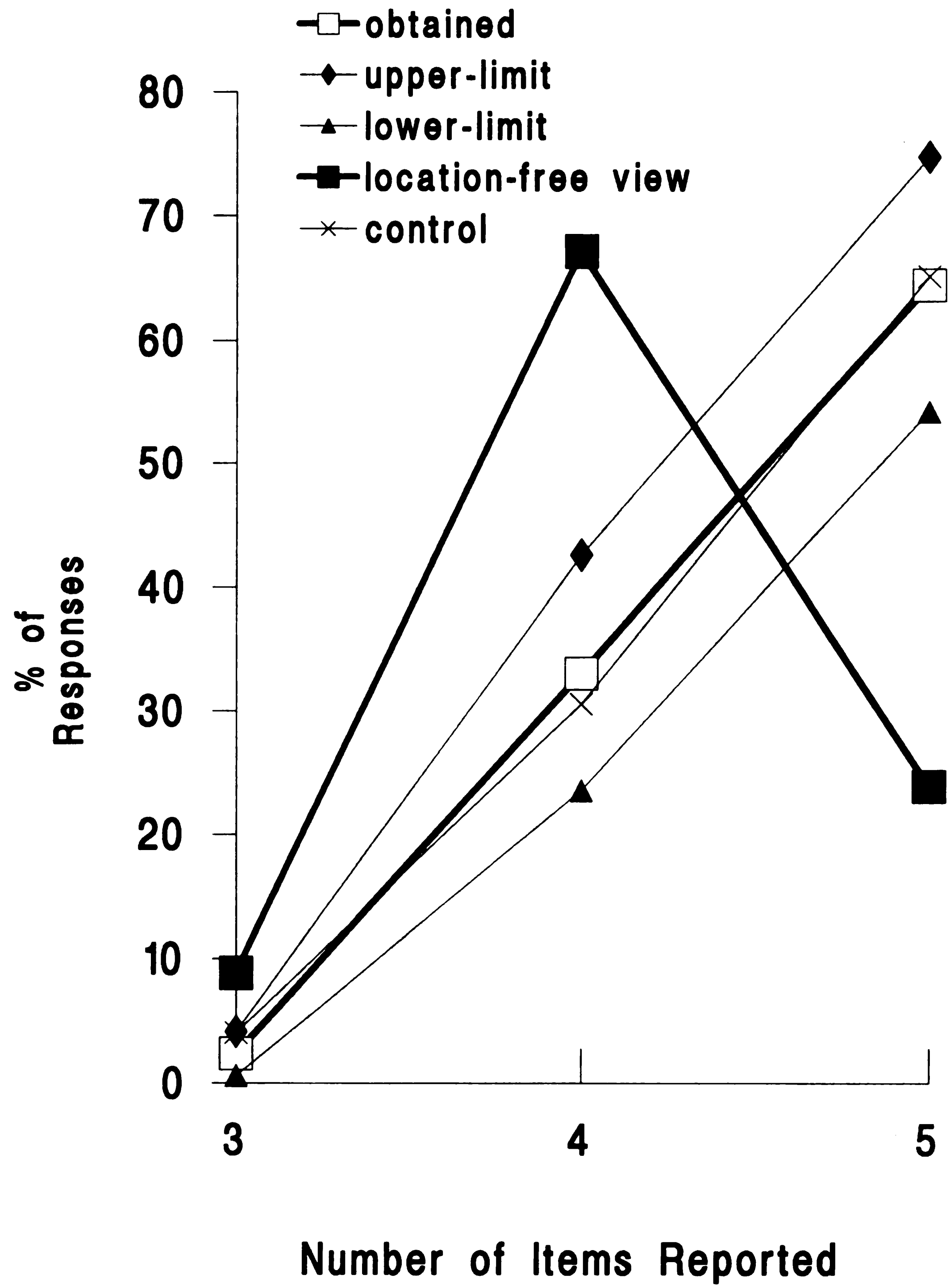

Figure 5. 95% confidence interval around obtained conjunction false-alarm responses, and the prediction by the location-free view (5 items in Experiment 1a).

The obtained counting response patterns were not different from the counting response patterns expected if there was no reduction in the number of items perceived when illusory conjunctions were experienced (see Table 4 and Figure 4 and Figure 5; see also Appendix B for individual data, and Appendix C for an alternative analysis, which leads to a similar pattern of results.

Experiment 1b.

The obtained and predicted counting response patterns of Experiment 1b are shown in Table 5 and in Figures 6 through 9. Again, significant differences between the predictions from the location-free view and the obtained data were found. In contrast, the obtained counting response patterns were not different from counting response patterns expected if there was no reduction in the number of items perceived when illusory conjunctions were experienced (see Table 5, and Figure 6 through 9; see also Appendix B for individual data, and Appendix C for an alternative that leads to a similar pattern of results).

Summary and Discussions of Experiment 1a, and 1b

To summarize, I obtained a significant amount of illusory conjunctions in Experiment 1a (7.3%), and 1b (12.4%). In other words, subjects more frequently reported targets from displays containing both horizontal lines and vertical lines (i.e., conjunction conditions) than from displays containing only horizontal lines or only vertical lines. The majority, but not all, of the individual subjects

Table 5. <u>95% Confidence Interval of Obtained Conjunction False-Alarm Counting Response Patterns, and the Prediction of the Location-Free View in Experiment 1b.</u>

stimuli	Counting Responses		
	3 items	4 items	5 items
X-present Displays			
4 items			
obtained data			
obtained	15.6	74.5	9.9
upper-limit	23.5	84.0	17.9
lower-limit	7.7	65.0	1.9
predicted data			
location-free	62.2*	33.4*	4.4
control+	20.7	71.0	8.3
5 items			
obtained data			
obtained	3.7	52.4	43.9
upper-limit	7.5	70.5	63.1
lower-limit	0.0	34.3	24.7
predicted data			
location-free	19.2*	63.5	17.3*
control	9.8	50.6	39.6
X-absent Displays			
4 items			
obtained data			
obtained	7.5	63.4	29.1
upper-limit	16.2	80.9	45.9
lower-limit	0.0	45.9	12.3
predicted data			
location-free	33.2*	47.7	19.1
control	12.8	64.8	22.4
5 items			
obtained data			
obtained	7.1	46.9	46.0
upper-limit	14.7	59.3	59.2
lower-limit	0.0	34.5	32.8
predicted data			
location-free	12.8	61.8*	25.4*
control	6.8	50.4	42.9

<u>Note</u> This analysis was based on the data from the subjects who showed positive illusory conjunctions (13 subjects and 15 subjects in x-displays and no x-displays, respectively.

* These data deviate from the 95% confidence interval of the obtained data.

+ This control indicates the counting response patterns expected if there was no reduction in the number of items perceived when illusory conjunctions occurred.

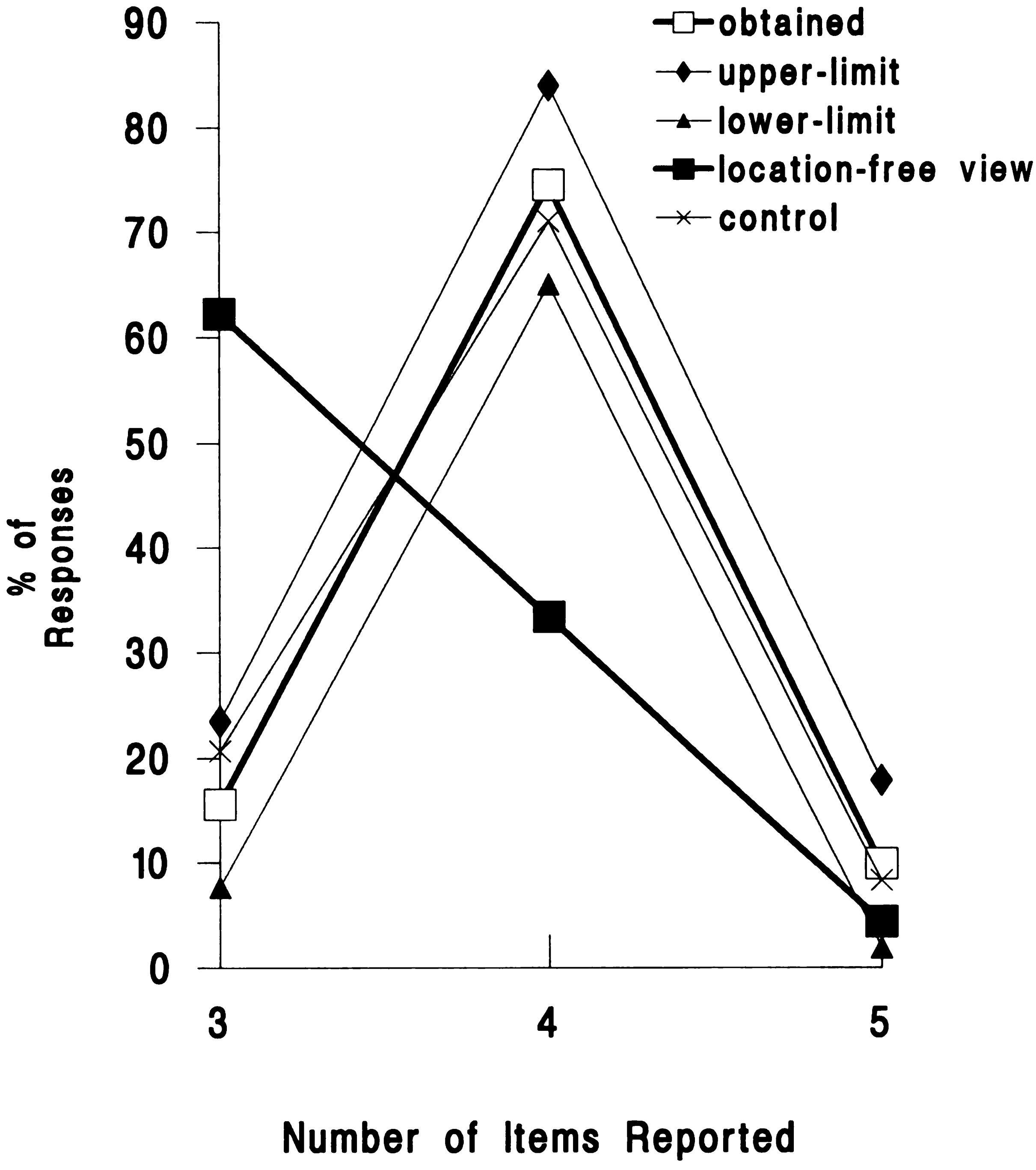

Figure 6. 95% confidence interval around obtained conjunction false-alarm responses, and the prediction by the location-free view (4 item x-displays in Experiment 1b).

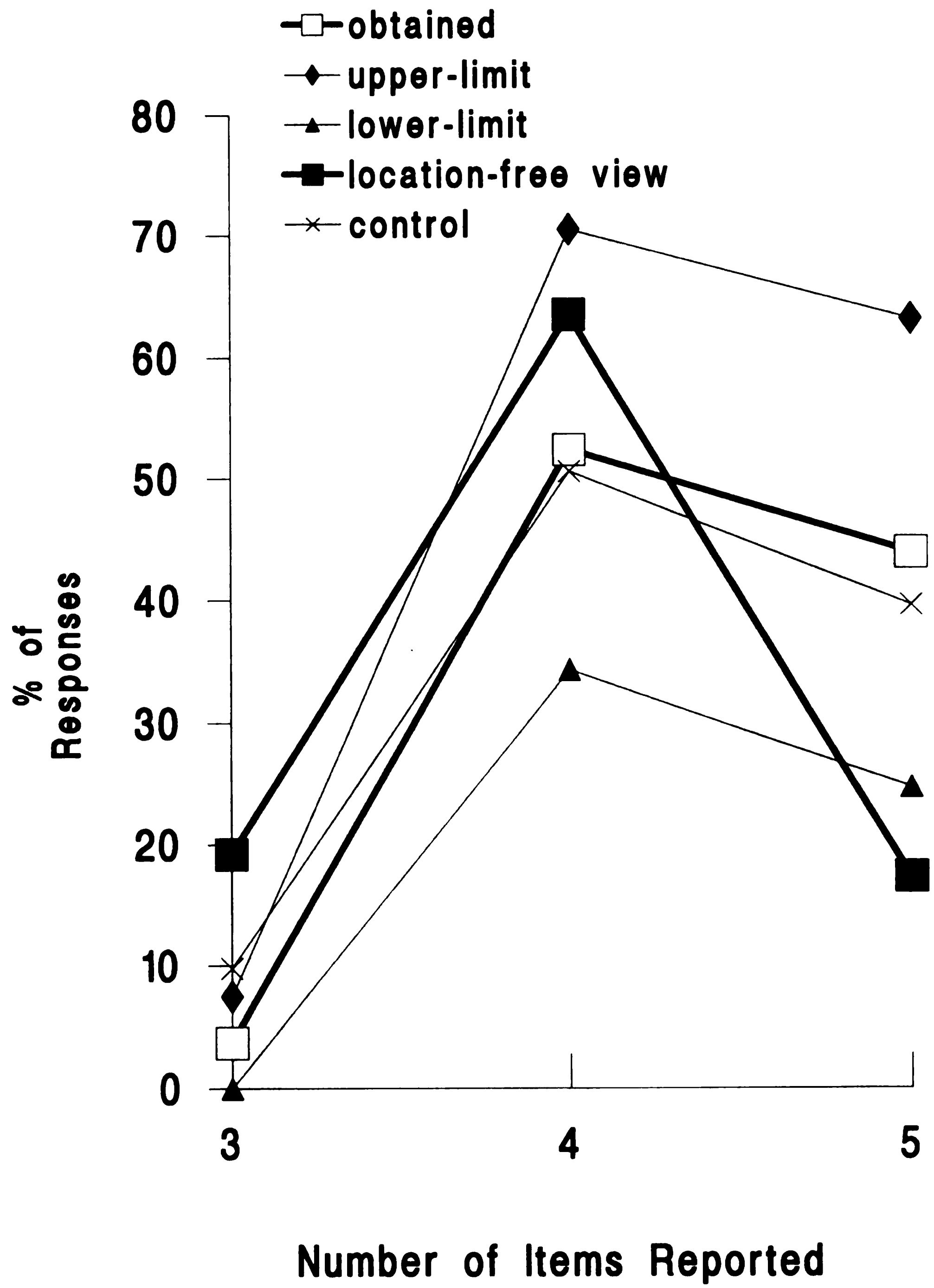

Figure 7. 95% confidence interval around obtained conjunction false-alarm responses, and the prediction by the location-free view (5 item x-displays in Experiment 1b).

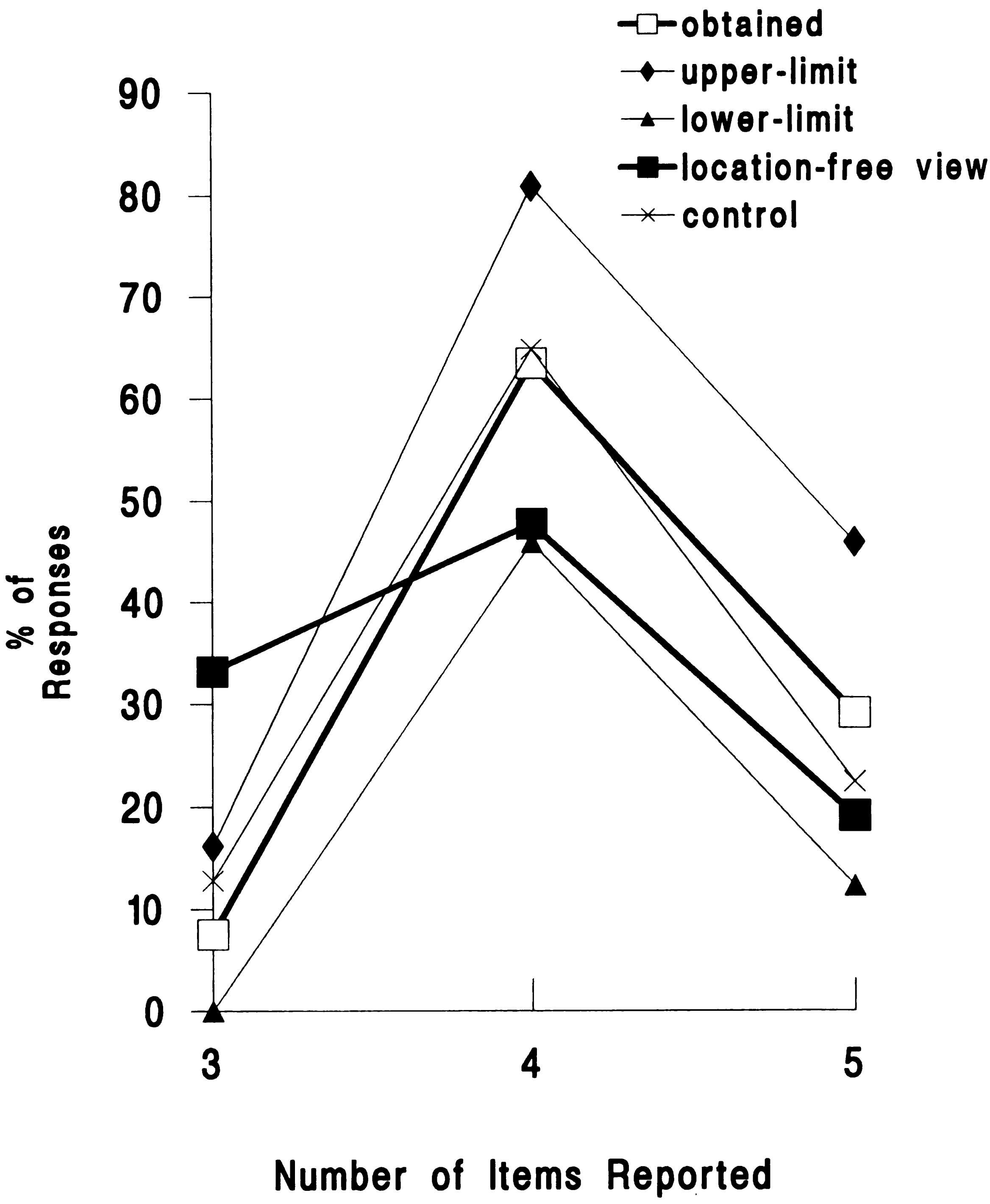

Figure 8. 95% confidence interval around obtained conjunction false-alarm responses, and the prediction by the location-free view (4 item no x-displays in Experiment 1b).

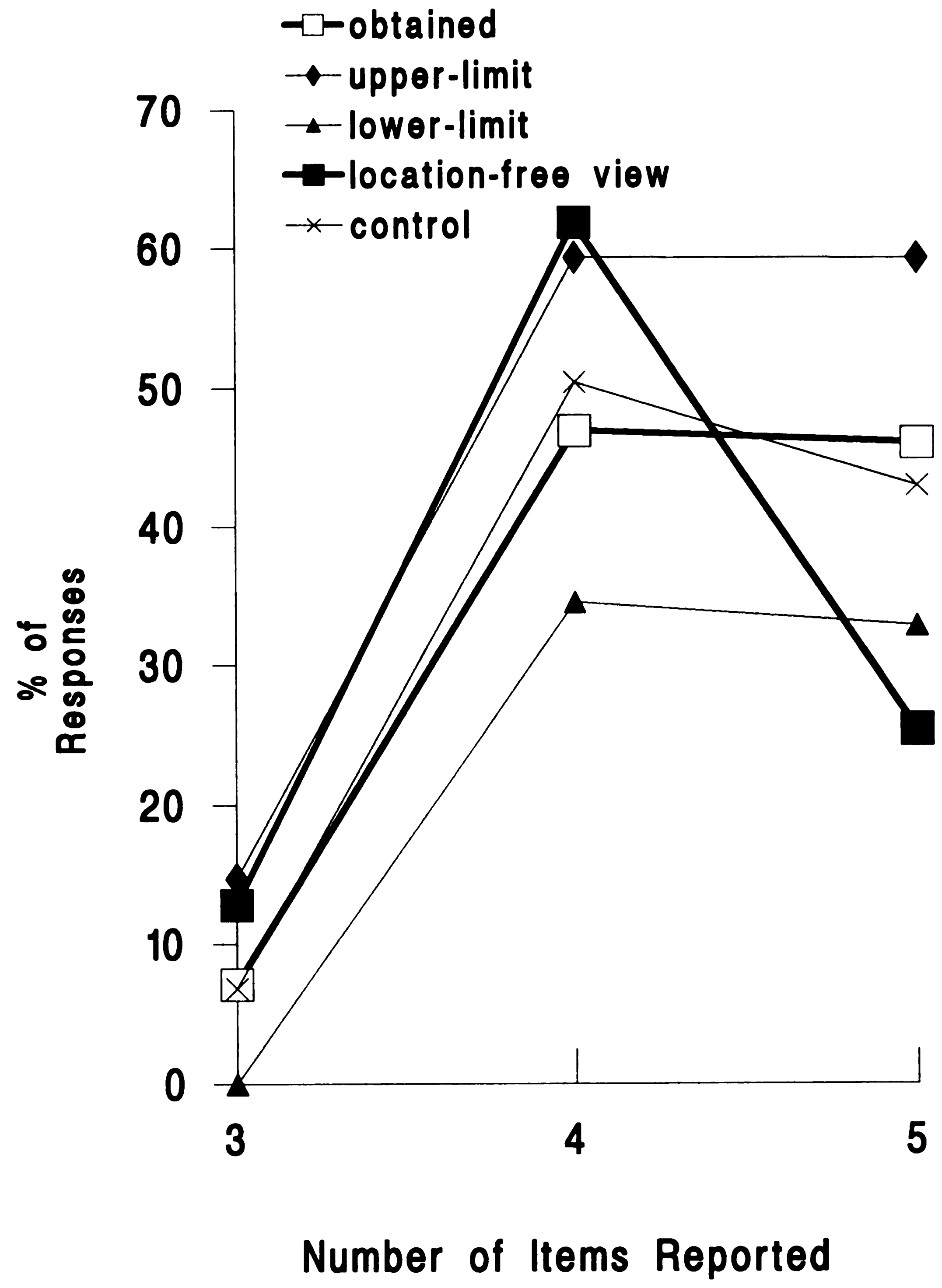

Figure 9. 95% confidence interval around obtained conjunction false-alarm responses, and the prediction by the location-free view (5 item no x-displays in Experiment 1b).

experienced illusory conjunctions. As described before, the location-free view explains the occurrence of illusory conjunctions by the assumption that feature codes lack their own location information.

Most importantly, the counting response patterns of conjunction false-alarms predicted by the location-free view deviated significantly from the obtained counting response patterns of conjunction false-alarms. That is, there were no suggestions that the numbers of items perceived was reduced when illusory conjunctions occurred in either Experiment 1a or 1b.

In Experiment 2a, 2b, and 2c, I examined the clarity of the percept formed in illusory conjunctions and compared them with that of the veridical target percept.

Experiments 2a, 2b, 2c

Experiments 2a, b, and c examined the location- free view with a different concurrent task (i.e., a confidence rating task). As mentioned earlier, the single representation view predicts no difference in confidence ratings between the real target percept and the percept of the illusorily combined target because the visual system does not distinguish the real percept from the illusory conjunction based percept.

I used the same detection task as in Experiment 1, but replaced the counting task with a confidence rating task. In other words, subjects were asked to rate their confidence in their responses (Experiment 2a). Because the estimated rate of occurrence of illusory conjunctions was small in Experiment 2a (there was a 2.9 percent difference between the feature false-alarm rate and the conjunction false-alarm rate), I added an 'x' to all of the displays to try to induce more illusory conjunctions by adding the feature of 'intersection' in Experiment 2b (Treisman & Paterson, 1984). In Experiment 2c, I combined Experiments 2a and 2b, and manipulated the presence of an 'x' as a within-subject variable.

Method

Subjects

Fifteen, twenty one, and twenty students participated in Experiments 2a, 2b, and 2c, respectively. They all reported normal color vision and were naive about the exact purpose of the experiments. Two subjects' data were discarded because one subject misunderstood the instructions (Experiment 2a), and one subject did not finish the whole experiment (Experiment 2b).

Apparatus and Stimuli

The apparatus of Experiments 2a, 2b, and 2c was exactly the same as in Experiment 1b. The same two computer systems described in Experiment 1b were used.

As described earlier, there were some variations in the stimuli across Experiment 2a, 2b, and 2c. The stimulus set of Experiment 2a was the same as that of Experiment 1a, with nine light blue circles as place holders and three to five items (horizontal lines, vertical lines, or a plus-sign). In Experiment 2b an extra 'x' was always presented in addition to the relevant stimuli in an attempt to induce subjects to perceive more illusory conjunctions[14]. In Experiment 2c, I combined Experiments 2a and 2b to permit a within-subject evaluation of the effect of adding an 'x' to the fillers as in Experiment 1b. An 'x' was randomly presented on half of the trials. In the displays containing an 'x', one of the fillers was dropped to equate the number of items in displays with and without an 'x'.

In Experiments 2a and 2b, I used a regular white dot pattern for masks as in Experiment 1a. In Experiment 2c, I used the same masks used in Experiment 1b, which contained parts of horizontal lines, vertical lines, and x's.

<u>Procedure</u>

The procedure for Experiments 2a and 2b was the same as that for Experiment 1a except for the following points. Subjects had to rate their confidence after they pressed the 'z' or '/' key on the computer keyboard to signal the presence or absence of the target. The possible confidence response was 1 (pure guess), 2, 3, 4, and 5 (sure). Subjects were not asked to count the items in the display. This confidence rating was asked only in the main phase of the experiments, not in the practice/threshold setting phase.

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This differed from the situation in Experiments 1b and 2c where an x replaced one of the fillers rather than simply being added to the display.

The lower limit of the presentation time was increased to 2 frames. In Experiment 2c, I used the procedure of Experiment 1b, and dropped the threshold setting stage. I started the duration at 9 frames and applied the duration-control rule used in Experiment 1a to displays containing an 'x' (x-displays) and displays containing no 'x' (no-x-displays) separately because pilot studies showed that the average duration in x-displays was longer than in no-x-displays.

In Experiment 2a and 2b, 5 blocks were run, whereas in Experiment 2c it was 6, and the first block was considered as a threshold-setting stage and not analyzed. The number of trials in each block was 96 in Experiment 2a and 2b, and 60 in Experiment 2c.

The stimulus duration averaged about 31 to 48 msec in Experiment 2a, 36 to 54 msec in Experiment 2b, 154 to 218 msec in x-displays of Experiment 2c, and 107 to 188 msec in no-x-displays of Experiment 2c. Block-by-block means are shown in Table 2.

Design

Experiment 2a and 2b contained three within-subject variables of Display Type ('feature', 'conjunction', and 'target present'), Numbers of Items (3, 4, and 5 items in Experiment 2a and 2c, and 4, 5, and 6 items in Experiment 2b), and Filler Type (horizontal lines or vertical lines). In Experiment 2c, another within-subject variable, the presence of an 'x'('x' or no 'x' only in Experiment 2c) was added.

Results and Discussions about Illusory Conjunctions

Experiment 2a

The error data of Experiment 2a are shown in Table 6. A three-way ANOVA was conducted on the false-alarm rates (%) of the feature and conjunction conditions. In this analysis, two levels of Display (feature and conjunction), three levels of Item Number (three, four, and five), and two levels of Filler (horizontal and vertical lines) were within-subject variables.

The main display-type effect was significant, $F(1, 13)=12.360$, $p<.005$ (M=12.6% in feature and 15.5% in conjunction displays) as was the interaction between display type and item number, $F(2,26)=10.720$, $p<.01$ (0.0%, 2.9%, and 5.9% estimated illusory conjunction error rates with 3, 4, and 5 items). Other main effects and interactions were not significant, with all p >.2.

Experiment 2b

The error data of Experiment 2b are shown in Table 6. As in Experiment 2a, a three-way ANOVA was conducted on the false-alarm rates (%) of the feature and conjunction conditions. In this analysis, two levels of Displays (feature and conjunction), three levels of Item Number (three, four, and five), and two levels of Fillers (horizontal and vertical lines) were within-subject variables.

The main display-type effect was significant, F(1,

Table 6. Average Error Rates(%) by Display Type for Experiments 2a, 2b, and 2c.

Display Type	Number of Items: three	four	five	average
Experiment 2a (without 'x')				
Miss in Target	2.1	3.1	3.5	2.9
FA in Feature	13.2	13.1	11.4	12.6
FA in Conjunction	13.2	16.0	17.3	15.5
means	13.2	14.6	14.4	
estimated IC rate	0.0	2.9	5.9	2.9
Experiment 2b (with 'x')				
Miss in Target	5.4	5.6	5.4	5.5
FA in Feature	13.3	15.8	17.9	15.7
FA in Conjunction	18.8	22.0	23.0	21.3
means	16.1	18.9	20.5	
estimated IC rate	5.5	6.2	5.1	5.6
Experiment 2c without x				
Miss in Target	10.0	14.8	14.0	12.9
FA in Feature	15.5	15.8	15.8	15.7
FA in Conjunction	30.8	28.8	29.0	29.5
means	23.2	22.3	22.4	
estimated IC rate	15.3	13.0	13.2	13.8
Experiment 2c with x				
Miss in Target	12.5	15.5	17.8	15.3
FA in Feature	17.3	19.0	20.3	18.9
FA in Conjunction	25.0	28.5	30.3	27.9
means	21.2	23.8	25.3	
estimated IC rate	7.7	9.5	10.0	9.0

Abbreviations FA = false-alarm responses in feature displays and conjunction displays; Miss = miss responses in target displays; IC = illusory conjunction. The estimated IC rate was computed by subtracting the FA rate in feature displays from the FA rate in conjunction displays.

19)=12.558, $\underline{p}<.005$ ($\underline{M}$=15.7% in features and 21.3% in conjunction displays). The main item number effect was also significant, $F(2,38)=6.558$, $\underline{p}<.005$ ($\underline{M}$=16.1%, 18.9%, and 20.5% error rates for 3, 4, and 5 items). Other main effects and interactions, including display-type and item-number interaction, were not significant, all $\underline{p}>.5$.

Again significant illusory conjunctions were obtained in the conjunction condition. Different from Experiment 2a, there was a main item-number effect but no interaction with display-type.

Between-Subject Analysis of Experiment 2a and 2b

I combined Experiments 2a and 2b and conducted a 4-way ANOVA with Experiments as a between-subject variable. Though display type and the number of items produced significant main effects, $F(1,32)=17.803$, $\underline{p}<.001$ in Display Type, and $F(2,64)=5.184$, $\underline{p}>.01$ in the Number of Items, there was no main effect of Experiment, $F(1,32)=.773$, $\underline{p}>.3$, and interactions with other variables were not significant, all $\underline{p}>.1$. In other words, the addition of an extra 'x' to displays did not increase error rates or the amount of the estimated illusory conjunctions.

Experiment 2c

The error data of Experiment 2c are shown in Table 7. A four-way ANOVA was conducted on the false-alarm rates (%) of the feature and conjunction conditions. In this analysis, two levels of 'x' (x-present or absent), two levels of Display (feature and conjunction), three levels of Item

Number (three, four, and five), and two levels of Fillers (horizontal and vertical lines) were within-subject variables.

The main display-type effect was highly significant, $F(1, 19)=157.552$, $p<.001$ ($M=17.3\%$ in feature and 28.7% in conjunction displays). The interaction between the presence of an 'x', Display Type and Fillers was also significant, $F(1, 19)=5.187$, $p<.05$ (12% and 6.2% estimated illusory conjunction rates for horizontal line fillers and vertical line fillers in x-displays; 11.3% and 16.3% estimated illusory conjunction rates for horizontal line fillers and vertical line fillers in no-x-displays). The main effect of Fillers ($M=24.1\%$ error rate in horizontal line fillers, and 21.9% error rate in vertical line fillers), and 'x' and Display Type interaction effect (9.1% and 13.8% estimated illusory conjunction rates for x-displays and no-x-displays) approached significance, $F(1, 19)=3.603$, $p=.073$, and $F(1, 19)=3.546$, $p=.075$ respectively. Other main and interaction effects were not significant, all $p > .19$.

In all three Experiments, the false-alarm rates in the conjunction conditions were higher than those in the feature conditions. In other words, illusory conjunctions occurred in the conjunction conditions. A main Item Number effect was obtained in Experiment 2b but not in Experiment 2a and 2c, while the interaction between Item Number and Display Type was significant in Experiment 2a but not in Experiments 2b and 2c. Because of this inconsistency, I did not consider the implications of the Item Number effect and of the interaction between Item Number and the amount of illusory conjunctions. Finally, in Experiment 2c, adding an 'x' did not make any difference in the total error rate or in the amount of illusory conjunctions, contrary to our expectation.

Results and Discussions about Confidence Rating

As explained earlier, I asked subjects to rate their confidence in their judgement about the presence of the target on a 1 to 5 scale. As in Experiments 1a and 1b, I required two steps for calculating the estimated confidence rating of the pure illusory conjunction component of the errors in the conjunction condition. The first step was to decompose false-alarms in the conjunction condition into a portion due to illusory conjunctions and a portion due to random errors, because the false-alarms in the conjunction condition could result both from the false combination of features and from random noise (Treisman & Schmidt, 1982). The illusory conjunction portion and random error portion were calculated by the formula,

$$IC_{prop} = (Conjunction_{error} - Feature_{error})/Conjunction_{error},$$

$$Random_{prop} = Feature_{error}/Conjunction_{error},$$

where IC_{prop} and $Random_{prop}$ are the proportion of illusory conjunctions and random errors, $Conjunction_{error}$ and $Feature_{error}$ are the conjunction and feature false-alarm rates.

The next step was to estimate the confidence rating of the pure illusory conjunction component, using the formula,

$$Conjunction_{cr} = (IC_{cr} * IC_{prop}) + (Feature_{cr} * Random_{prop}),$$

where $Conjunction_{cr}$ and $Feature_{cr}$ are the obtained confidence rates of the conjunction false-alarms and feature false-alarms, IC_{cr} is the estimated confidence rate of the pure illusory conjunctions, and IC_{prop} and $Random_{prop}$ are the proportion of illusory conjunctions and random errors. This formula can be rewritten as follows,

$$IC_{cr} = (Conjunction_{cr} - Feature_{cr} * Random_{prop})/IC_{prop}.$$

The confidence ratings of hit responses, of false-alarm responses in the feature condition, of false-alarm responses in the conjunction condition, and the estimated confidence ratings of illusory conjunctions are shown in Table 7. As in Experiments 1a and 1b, I used data for only those subjects who showed more conjunction false-alarms than feature false-alarms, because the occurrence of illusory conjunctions was prerequisite to examining the location-free view. One subject in Experiment 2a, three subjects in Experiment 2b, three subjects in the x-present condition of Experiment 2c, and five subjects in the x-absent condition of Experiment 2c were discarded because of this criterion, and two more

Table 7. <u>The Average Confidence Ratings of a Real Plus-sign in Target Displays, and the Average Confidence Ratings of the False Perception of a Plus-sign in Conjunction Displays, and in Feature Displays (Experiments 2a, 2b, and 2c).</u>

	Exp 2a	Exp 2b	Exp 2c without 'x'	Exp 2c with 'x'
real plus in TD (A)	4.81	4.66	4.56	4.50
false plus in CD (B)	3.38	2.80	3.34	3.47
false plus in FD (C)	2.86	2.68	2.62	3.35
estimated confidence (D)	3.70	3.03	3.85	3.95
t-test (A and D)	p<.05	p<.001	p<.05	p<.05
t-test (C and D)	.05<p<.1	p>.1	p<.001	.05<p<.1

<u>Abbreviations</u> TD=target displays; CD= conjunction displays; FD=feature displays

<u>Note</u> T-tests were conducted comparing the confidence ratings of the real plus perception in target displays to that of the false perception of a plus in the conjunction displays, and the confidence ratings of the false perception of a plus in the conjunction displays to that of the false perception of a plus in the feature displays.

subjects were discarded because they were not confident even of their hit responses (M=1.9 and 1.2 respectively, whereas for the remaining subjects M=4.8, SD=.32 in overall).

I conducted t-tests between hit confidence ratings and the estimated confidence ratings of illusory conjunctions. In Experiment 2a, the estimated confidence ratings of illusory conjunctions (M=3.70, SD=1.33) were significantly different from hit confidence ratings (M=4.81, SD=.32), $t(10)=2.853$, $p<.05$.

Experiments 2b, and 2c also revealed significant differences in confidence ratings, M=3.03 (SD=.93) vs. 4.66 (SD=.34), $t(16)=7.593$, $p<.001$ in Experiment 2b; M=3.95 (SD=1.16) vs. 4.50 (SD=.42), $t(16)=2.349$, $p<.05$ in x-displays of Experiment 2c; M=3.85 (SD=1.00) vs. 4.56 (SD=.44), $t(14)=2.812$, $p<.05$ in no-x-displays of Experiment 2c.

As can be seen, the confidence rating data were inconsistent with the location-free view. This data pattern did not change whether an extra 'x' was present (Experiments 2b and 2c) or whether white masks (Experiments 2a and 2b) or pattern masks (Experiment 2c) were used. That is, subjects were less confident of their responses when they reported a target from conjunction displays than when they reported a target from target displays.

Finally, I compared the feature false-alarm confidence ratings with the estimated confidence ratings of illusory conjunctions. The difference between the two confidence ratings was significant in one case and approached significance in the others, $\underline{M}=2.86$ (SD=1.32) vs. 3.70 (SD=1.33), $t(10)=1.983$, $\underline{p}=.076$ in Experiment 2a; $\underline{M}=2.68$ (SD=.94) vs. 3.03 (SD=.93), $t(16)=1.591$, $\underline{p}=.131$ in Experiment 2b; $\underline{M}=3.35$ (SD=.98) vs. 3.95 (SD=1.16), $t(16)=1.806$, $\underline{p}=.09$ in x-displays of Experiment 2c, and 2.62 (SD=1.23) vs. 3.85 (SD=1.00), $t(14)=4.817$, $\underline{p}<.001$ in no-x-displays of Experiment 2c). There was a tendency for the estimated confidence rating of illusory conjunctions to be higher than that of feature false-alarms. Given the assumption that feature false-alarm responses result from random-noise in the visual input, this difference in confidence ratings is expected by the location-free view.

Summary of Experiments 1 and 2

The results from Experiments 1a, 1b, 2a, 2b, and 2c can be summarized as follows. First, though illusory conjunctions were sometimes observed there was no hint of a reduction in the number of items perceived (Experiments 1a and 1b). This data pattern did not change, whether white masks or pattern masks were used or an extra 'x' was added (Experiment 1b). Second, the estimated confidence ratings of illusory conjunctions were significantly lower than hit confidence ratings ($\underline{M}=3.48$ vs. 4.51 in Experiment 2a; $\underline{M}=3.03$ vs. 4.66 in Experiment 2b; $\underline{M}=3.95$ vs. 4.50, and $\underline{M}=3.85$ vs. 4.56 in x-displays and no-x-displays of Experiment 2c).

Thus it is tempting to doubt the location-free view of illusory conjunctions both from the counting response patterns and the confidence rating patterns.

CHAPTER III: ILLUSORY CONJUNCTIONS WITHIN AND BETWEEN DIMENSIONS

Introduction

Although counting response patterns and confidence rating patterns were obtained that challenged the location-free view in experiments 1 and 2, those experiments all used what Treisman would call intradimensional stimuli. In Experiments 1 and 2 I used different feature values of the same dimension (see Treisman, 1989 for the definition of dimensions and features). In other words, I examined illusory conjunctions between two different feature values (horizontal lines and vertical lines) of the same dimension (line orientation).

However, Treisman and Schmidt (1982) showed that illusory conjunctions could also be obtained between different features of different dimensions (e.g., form and color), and when they asked questions similar to ours with interdimensional stimuli, they obtained the opposite answers[15].

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Note that Treisman and her colleagues did not ask the same questions as ours with intradimensional stimuli.

Treisman and Schmidt(1982)

In their Experiment 1, Treisman and Schmidt(1982) asked whether features left any traces behind after they moved to other locations to form illusory conjunctions, and they obtained results supporting their location-free view. Specifically, they presented three different letters (e.g., T, N, and X) of different colors (e.g., pink, green, and brown) with a digit at each side and asked subjects to report the two side-digits first and then to report the colored letters. In addition, they included some trials on which either two colors or two letters were the same, assuming that because some trials contained duplications of features, subjects would feel free to report repeated colors or letters when one of them was an illusory conjunction. But they did not find any evidence for illusory repetitions even though subjects sometimes reported colors and forms of different objects to belong to the same object (i.e., illusory conjunctions). This failure to observe illusory repetitions led Treisman and Schmidt (1982) to conclude that a feature is perceived only once without leaving any ghosts behind when they are illusorily combined.

Moreover, when subjects were asked to describe what they saw or thought they saw, they used the "doubtful" category in 0.04 items per trial when their responses were hits, and for 0.05 items per trial when their responses were conjunction false-alarms, while they used the "doubtful" category for 0.16 items per trial when their responses were feature false-alarms. In other words, the confidence rating of the illusory conjunction based percept was hardly different from that of the real percept.

Comparison between This Study and Treisman and Schmidt (1982)

How can I reconcile the data from Experiments 1 and 2 in this study with Treisman & Schmidt (1982)? I found that illusory conjunctions were not accompanied by the reduction in the number of items perceived, which implies that visual features are contingent on their location or at least leave some traces behind, so that subjects could count items correctly even when they experienced illusory conjunctions. In contrast, Treisman and Schmidt (1982) argued that features did not leave any traces behind after they moved to other locations to form illusory conjunctions. I found that the perceptual clarity of the plus-sign resulting from illusory conjunctions was lower than that of the real plus-sign, while Treisman and Schmidt (1982) reported that the confidence rating of the illusory conjunction based percept was hardly different from that of the real percept. One possible solution is to rely on the difference which might exist between mechanisms underlying interdimensional representation and intradimensional representation, and another solution is to look for task differences between the two studies.

Two Underlying Mechanisms of Inter- and Intradimensional Conjunctions of Features

As Treisman recognized (Treisman & Paterson, 1984), "conjunctions of lines, angles, curves, and other simple components of shape have another characteristic that does not apply to conjunctions of color and shape" (p.15). Unlike the color-form combination, some combinations of simple form features appear to generate new interactive or relational properties. In addition, it is impossible to remove one form feature without causing a change in the form dimension. For example, if a horizontal line is combined with a vertical line, a new property called a 'plus' (or intersection) is generated. And if a horizontal line component is removed from the plus, the resulting percept is no longer the plus. Thus, form features are interdependent in making the percept.

In contrast, the relationship between the color and form dimensions is different. We can change or remove any dimension without changing the other dimension. For example, I can imagine a red circle as well as a blue circle, and the circular form does not change when the color of the circle is replaced by another color. Color features are separable from form features in making a percept (Garner, 1970).

Therefore, one way to reconcile the data obtained in Experiments 1 and 2 with Treisman and Schmidt (1982) is to assume that two different mechanisms underlie illusory conjunctions of inter- and intradimensional features. For example, the location-free view might be valid at least in the interdimensional situation, such as between color and form, though another mechanism underlies the intradimensional illusory conjunctions.

Task Differences

The second way to resolve the conflict might be to analyze the differences between tasks used in Experiments 1 and 2 and the tasks used in Treisman and Schmidt (1982). For example, in Treisman and Schmidt's (1982) Experiment 1, subjects were asked to report colored letters, but there was no predefined target set to be searched for, and they chose features maximally discriminable from each other (p.114). Therefore, subjects might have perceived all of these features as equally salient, and this saliency might have led subjects to ignore faint traces they might otherwise have perceived. Suppose the figures presented between the two digits are a red circle, a green square, and a blue triangle. If subjects perceived a red circle correctly, but a green triangle falsely, the possible percept found from the remaining features would be a blue square, not a green square or a blue triangle because the saliency of the remaining features (i.e., the blue color feature and square form feature) would be preferentially used for responses compared with the faint repeated traces (see p. 12 of Treisman & Souther, 1986, for similar arguments).

The Purpose of Experiments 3 and 4

The purpose of Experiments 3 and 4 was to examine these two possibilities by employing our counting and confidence rating tasks in an interdimensional situation. Specifically, in Experiments 3 and 4 I replaced the plus target of Experiment 1 with a red line, and the fillers (horizontal lines and vertical lines) with white horizontal lines and red color. As in Experiments 1 and 2, each trial could contain white horizontal lines, red color without form (see the method section of Experiment 3 for details), or red horizontal lines. Subjects were asked to search for a red horizontal line (i.e., a pre-defined target) among fillers that were either a white horizontal line or only the color red. Some trials included fillers of only one type (i.e., the feature condition) and others included both types (i.e., the conjunction condition). In Experiment 3, a counting task was added to the target search task as in Experiment 1, while in Experiment 4 a confidence rating task was included as an auxiliary task.

The conflict between our data in Experiments 1 and 2 and Treisman and Schmidt (1982) may imply the existence of two different mechanisms, one of which underlies interdimensional representations and the other intradimensional representations. If so, we would expect to find a reduction in the number of items perceived in illusory conjunctions, and a lower confidence rating of the false percept based on illusory conjunctions than that of the real target percept. In contrast, if the conflict is attributable to the differences between tasks used in the two studies, the same results are expected as in Experiments 1 and 2 in this study.

CHAPTER IV: COUNTING AND CONFIDENCE RATING IN ILLUSORY CONJUNCTIONS BETWEEN DIMENSIONS

In Experiments 3 and 4, I replicated the designs of Experiments 1a, and 2a but using an interdimensional stimulus set. In Experiment 3, I added a counting task to an illusory conjunction task to examine whether illusory conjunctions were accompanied by the reduction of the number of items perceived. In Experiment 4, I asked subjects to rate their confidence in their responses about the presence of the target in each display in order to compare the perceptual quality of the real target percept and the illusorily formed percept. As can be seen, the color red and a horizontal line were chosen for the interdimensional stimulus set.

Experiment 3: Form/Color Dimensions with Counting

Methods

Subjects

Twenty two students who were taking Introductory Psychology courses were recruited for this experiment. They reported normal color vision and were naive about the exact purpose of this study. Two subjects were replaced because one subject reported severe astigmatism and the other subject showed a strong bias to report four items in the counting task.

Apparatus and Stimuli.

The apparatus and stimuli were the same as in Experiment 1a except that the vertical lines were replaced by red color and color/form masks were used instead of white masks or pattern masks. The color/form masks were made of short horizontal lines in white or in red (see Figure 2).

Two features used in this experiment were a form feature and a color feature. For the color feature, I used red, and for the form feature horizontal lines (of Experiments 1 and 2) were used. Unlike Treisman and Schmidt (1982), where each item consisted of both form and color features, I used items (not targets) made of only one feature (a color feature or a form feature), lest subjects count items based on the other remaining feature (see Experiment 1a). Because it is logically impossible to make color feature items without any form, the corresponding outline circles were painted in red without any form feature inside[16]. In other words, form feature items consisted of

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Strictly speaking, even the items used in this study contained both color and form features. For example, I used white horizontal lines for the form feature without the color, and red outlined circles for the color feature without the form. Obviously, a white horizontal line contains the color of white as well as the form property of horizontality, and a red circle contains the form of a circle as well as the color of red. However, the white color and circular form were not relevant features to the tasks.

only one form feature, which was an achromatic horizontal line without a relevant color feature, and color feature items consisted of only a color feature without a form feature, which was the color of the place holding circles. Examples of the displays are shown in Figure 1.

Procedure and Design

The procedure was the same as that of Experiment 1a except for the duration-control rule, which was adopted from Experiment 1b. That is, subjects had to report their count of horizontal lines or colored circles (instead of vertical lines) after they reported whether or not a target (red horizontal line) was present. The possible numbers of horizontal lines and colored circles were 3, 4, and 5. The experimental design was the same as that of Experiment 1a except that there was no between subject manipulation of the trial-type probabilities.

Results

The stimulus duration averaged about 141 to 194 msec. Block-by-block means are shown in Table 2. The miss ('no' responses in target displays) and false-alarm ('yes' responses in feature displays and in conjunction displays)

(continued from the previous footnote)
In Experiments 3 and 4, only one feature of the items was relevant to the task. In pilot experiments, I used white circles filled with red for color feature items and failed to obtain a significant amount of illusory conjunctions (7.3% in the feature condition vs. 6.4% in the conjunction condition, $F(1,19)=0.712$, $p=.409$, see Appendix D for details), so we chose empty red circles for the stimulus set.

Table 8. Average Error Rates(%) for Target Displays, Feature Displays, and Conjunction Displays in Experiment 3.

Display Type	Number of Items: three	four	five	average
using 20 subjects				
(form filler)				
Miss in Target	4.4	4.3	4.1	4.3
FA in Feature	4.8	4.8	7.9	5.8
FA in Conjunction	6.1	5.3	7.3	6.2
means of FAs	5.5	5.1	7.6	
estimated IC	1.3	0.5	-0.6	0.4
(color filler)				
Miss in Target	7.8	11.0	11.6	10.1
FA in Feature	3.8	5.8	3.3	4.3
FA in Conjunction	7.8	11.4	13.3	10.8
means of FAs	5.8	8.6	8.3	
estimated IC	4.0	5.6	10.0	6.5
using 13 subjects+				
(form filler)				
Miss in Target	4.2	5.0	4.6	4.6
FA in Feature	6.2	5.4	10.0	7.2
FA in Conjunction	5.8	6.5	8.8	7.0
means of FAs	6.0	6.0	9.4	
estimated IC	-0.4	1.1	-1.2	-0.2
(color filler)				
Miss in Target	7.7	10.8	11.2	9.9
FA in Feature	1.9	3.1	3.1	2.7
FA in Conjunction	6.9	14.2	12.3	11.1
means of FAs	4.4	8.7	7.7	
estimated IC	5.0	11.1	9.2	8.4

Abbreviations FA = false-alarm responses in feature displays and conjunction displays; Miss = miss responses in target displays; IC = illusory conjunction. The estimated amount of IC was computed by subtracting FA in feature displays from FA in conjunction displays.

+ The values inside the parentheses are the data from 13 subjects whose data were used for the analysis of confidence ratings (see the text).

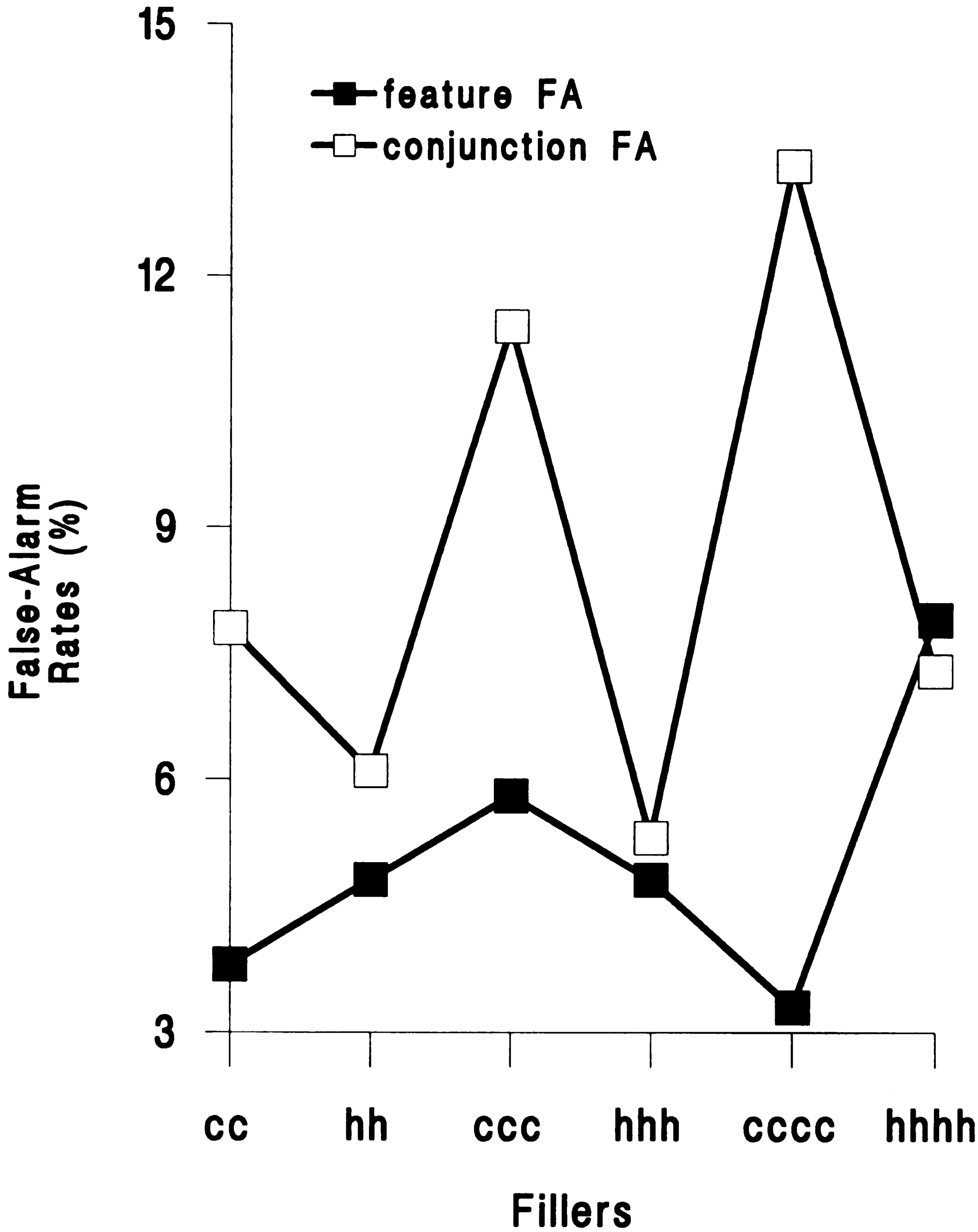

Figure 10. Average false-alarms of the feature condition and the conjunction condition as the function of fillers and display size in Experiment 3.

rates are shown in Table 8 and Figure 10.

Again, the data analysis was performed in two steps to answer two questions: Were illusory conjunctions obtained in this task, and did the counting error pattern depend on the display type?

Illusory Conjunction Phenomenon

The rate of illusory conjunctions was computed by taking the difference between the false-alarm rates of the feature condition and the conjunction condition. A three-way ANOVA was conducted on the false-alarm rates (%) of the feature and conjunction conditions. In this analysis, two levels of Display (feature and conjunction), three levels of Item Number (three, four, and five), and two levels of Filler (form filler and color filler) were within-subject variables.

The main Display effect was significant (M=5.1% in the feature condition vs. 8.4% in the conjunction condition), $F(1,19)=12.621$, $p<.005$, and the interaction between the Display and Filler was also significant (see below), $F(1,19)=18.045$, $p<.001$. The nature of this interaction is obvious in Table 8 and Figure 10. That is, the Display effect was only significant with the color fillers (M=4.3% in the feature condition and 10.8% in the conjunction condition) but not with the form fillers (M=5.8% in the feature condition and 6.2% in the conjunction condition). The number of items produced marginal differences in false-alarm rates (M=5.7%, 6.9%, and 8.0% in 3 item, 4 item , and

5 item displays), $F(2,38)=2.759$, $.05<p<.1$ There were no other significant effects or interactions.

The higher false-alarm rate in the conjunction condition than in the feature condition implies that there were illusory conjunctions in the conjunction condition. The estimated amount of illusory conjunction was 3.3% overall and 6.5% in color filler displays.

One unexpected result was that there was no difference between the feature false-alarm rate and the conjunction false-alarm rate if horizontal lines were used as fillers. One possibility is that the saliency of the color feature was greater than the form feature, so that the red color captured subjects' attention more strongly than the form feature. For example, when subjects were presented with three white horizontal lines and one red circle, the red circle might have captured their attention. In that case, subjects could identify the contingency between the red and the circle, and the remaining three white horizontal lines did not leave any space for illusory conjunctions because the red color was no longer available. In contrast, when subjects were presented with three red circles and one white horizontal line, neither the red circles nor the horizontal line would have captured their attention. In that case the red color of one of the circles and the white horizontal line might have falsely combined to produce an illusory conjunction. Even when one red circle captured subjects attention, it is possible that the red color of the other two red circles and the white horizontal line might have combined to produce an illusory conjunction.

Another possibility is that pre- and postmasks interacted with the stimulus displays differentially with color fillers and form fillers. The masks that were used were intended to prevent perceptual persistence of the stimulus displays, but there might have been an interaction between the type of target display and the masks. The feature displays with the form filler contained only white horizontal lines without any red color, and the form filler conjunction displays contained red color as well as white horizontal lines. If the red color of the pre- or postmasks was added to stimulus displays, I would expect no difference between the feature false-alarm rate and the conjunction false-alarm rate because feature displays as well as conjunction displays would now contain both the red color feature and the horizontal line form feature. However, in the case of the color fillers there might not have been this kind of interaction because only fragments of the horizontal lines were used in masks, which were different from horizontal line features in the stimulus displays.

I prefer the first possibility to the second for three reasons. First, the second possibility implies that the false-alarm rates in both the feature and the conjunction conditions with form fillers should have error rates as high as for the conjunction condition with color fillers, but that is not what happened in the data (see Figure 10).

Second, if the lack of illusory conjunctions (i.e., no difference between feature false-alarm rate and the conjunction false-alarm rate) in the form filler displays resulted from the interaction between the stimulus display and pre- postmasks, it might be attributable to the increased feature false-alarm rate rather than to the decreased conjunction false-alarm rate. In contrast, if the absence of illusory conjunctions in form filler displays resulted from the saliency of the color feature, it would be accompanied by a decreased conjunction false-alarm rate rather than the increased feature false-alarm rate. As is clear in Table 8, the feature false-alarm rates in form filler displays and color filler displays were roughly equivalent (M=5.8% vs. 4.3%), while the conjunction false-alarm rate with form filler displays was much lower than that of color filler displays (M=6.2% vs. 10.8%).

Lastly, if the saliency of the color captured subjects' attention, subjects should show lower miss rates with form fillers because when subjects were presented with three white horizontal lines and one red horizontal line, the red horizontal line (i.e., a target) was more likely to capture their attention, allowing them to make a correct response. But when subjects were presented with three red circles and one red horizontal line, subjects could not have enjoyed such a benefit in the target search. In contrast, with the interaction between stimulus displays and pre- postmasks there is no reason for the miss rate to depend on the filler type. The obtained miss rates were consistent with the first possibility (M=4.3% with the form fillers vs. 10.1% with the color fillers, $t(19)=3.318$, $p<.005$).

Because a significant amount of illusory conjunctions is prerequisite to examining the location-free view and the dual code view, I used only the color filler data in analyzing the counting responses.

Counting Responses

I again used the two-step procedure to calculate counting response patterns for conjunction false-alarms predicted by the location-free view. The same logic used in Experiments 1a and 1b was used to compute counting patterns predicted by the location-free view. The obtained data and predicted counting response patterns are shown in Table 9, Figure 11 and Figure 12.

Significant deviations between the predictions by the location-free view and the obtained data were found in responding 'three' and 'four' in four item displays (obtained: 56.0% vs. predicted: 0.7% - 27.7%; obtained: 33.7% vs. predicted: 47.3% - 83.9%), and in responding four and five in five item displays (obtained: 64.6% vs. predicted: 15.8% - 61.2%; obtained: 27.7% vs. predicted: 31.2% - 78.0%). In contrast, the obtained counting response patterns were not different from the counting response patterns expected if there was no reduction in the number of items perceived when illusory conjunctions occurred.

Table 9. 95% Confidence Interval[a] of Obtained Conjunction False-Alarm Counting Response Patterns, and the Prediction of the Location-Free View in Experiment 3.

	counting responses		
	three	four	five
4 items			
Obtained Data			
obtained data	14.1	65.6	20.3
lower limit	27.7	83.9	37.1
upper limit	0.7	47.3	3.5
Predicted Data			
location-free	56.0*	33.7*	10.3
control+	6.4	71.4	22.2
5 items			
Obtained Data			
obtained data	6.9	38.5	54.6
lower limit	0.0	61.2	78.0
upper limit	16.2	15.8	31.2
Predicted Data			
location-free	7.7	64.6*	27.7*
control+	5.9	21.0	73.1

[a] The lower-, and upper limits of obtained data were computed using formula, $X - 1.96e_{standard} < M < X + 1.96e_{standard}$. Here, X is the obtained value of each counting response, *M* is the parameter value, and $e_{standard}$ is the standard error of each obtained sample mean ($e_{standard}$ = SD/the square root of the sample size,N). This analysis was conducted on the 13 of the 20 subjects who showed positive illusory conjunctions both in four item displays and in five item displays (see also Appendix B for individual data, and Appendix C for an analysis using an alternative formula which leads to a similar pattern of results).

* The 95% confidence interval around the data does not contain the predictions.

\+ This control indicates the counting response patterns expected if there was no reduction in the number of items perceived when illusory conjunctions occurred.

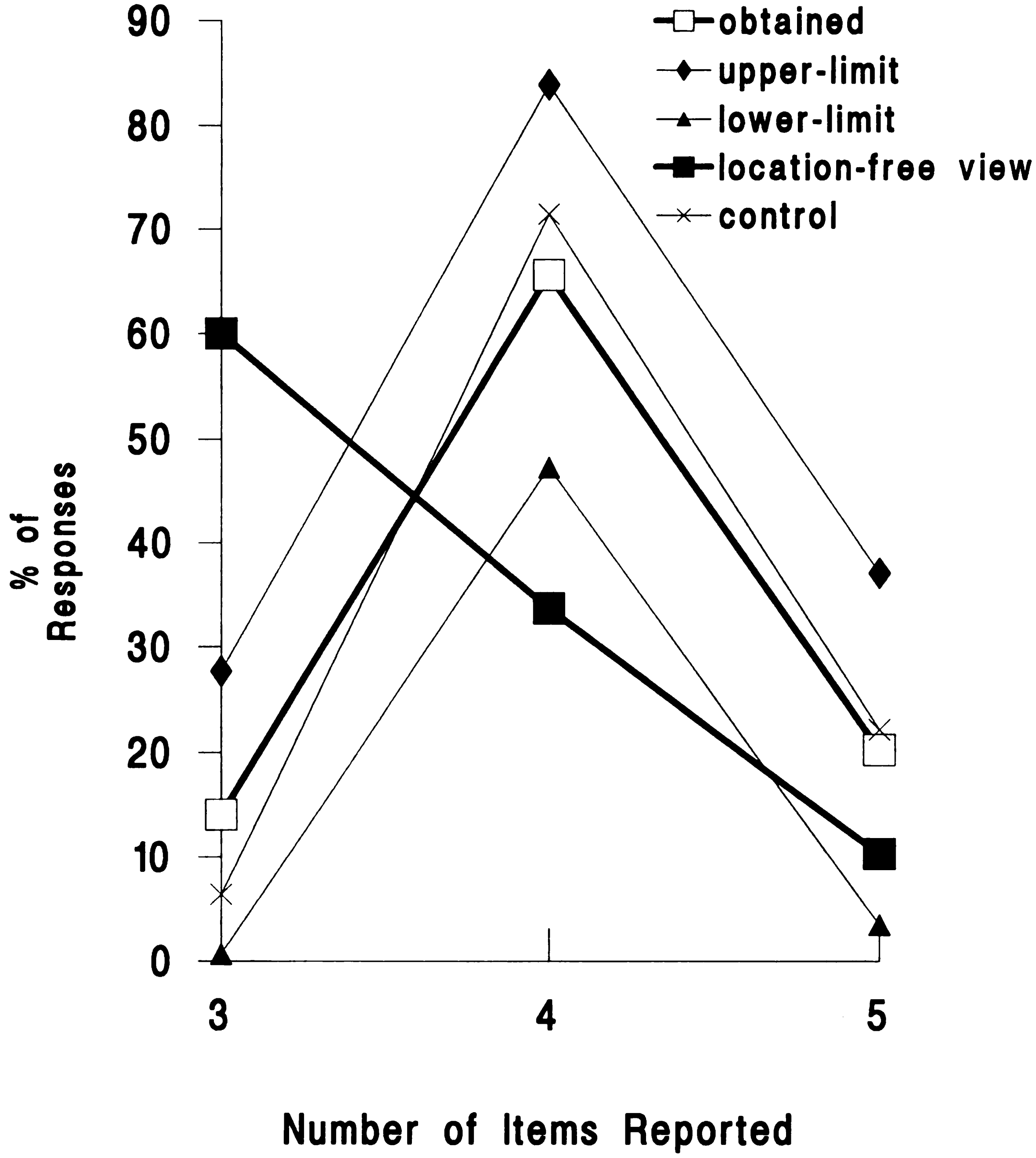

Figure 11. 95% confidence interval around obtained conjunction false-alarm responses, and the prediction by the location-free view (4 items in Experiment 3).

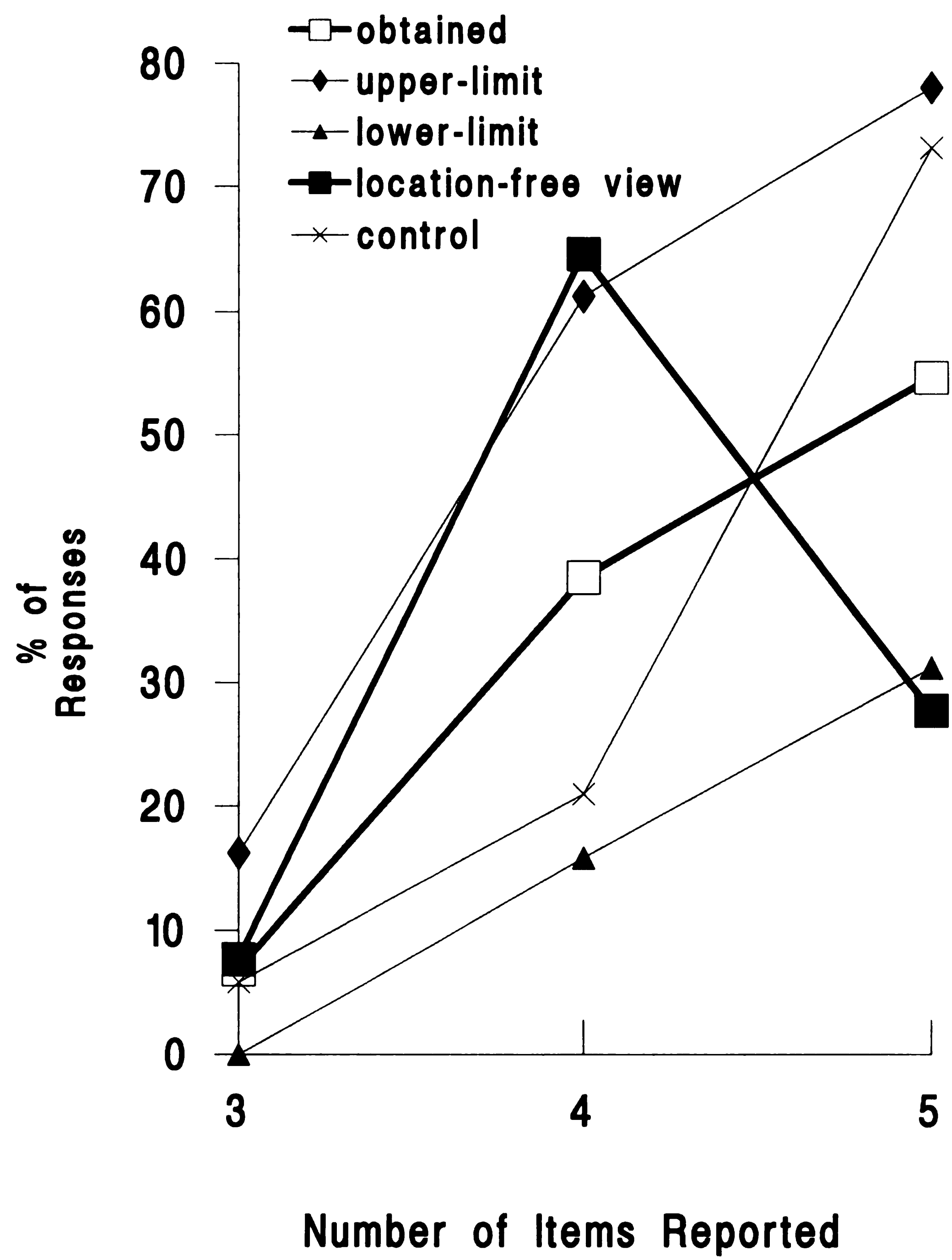

Figure 12 95% confidence interval around obtained conjunction false-alarm responses, and the prediction by the location-free view (5 items in Experiment 3).

Discussion

Again I obtained a significant rate of illusory onjunctions, although only in color filler displays. But there was no reduction in the number of items perceived when illusory conjunctions were experienced. With these data, it is tempting to conclude that the absence of illusory repetitions in Treisman and Schmidt (1982) might result from the specificity of the tasks they used, and that the features that produced illusory conjunctions seem to leave (at least) their traces at the original locations.

Experiment 4: Form/Color Dimensions with Confidence Ratings

Experiment 4 was a replication of the design of Experiment 2a but using an interdimensional stimulus set. As mentioned earlier, I examined the perceptual quality of the real target percepts and the percepts of illusory conjunctions. Subjects were asked to rate their confidence in their responses after reporting on the presence of a target. As in Treisman and Schmidt (1982), if these two percepts are undistinguishable (there are no differences between their confidence ratings), I have to distinguish between mechanisms underlying illusory conjunctions within the form dimension (intradimensional) and between the color dimension and the form dimension (interdimensional). In contrast, if the confidence rating of the illusory percept is lower than the rating of the real target percept, I could extend the conclusion I made about form dimension illusory conjunctions to the form and color dimension illusory conjunctions.

Method

Subjects

Twenty students in the Introductory psychology course were recruited for this experiment. They reported normal color vision and were naive about the exact purpose of the study.

Apparatus and Stimuli

The apparatus and stimuli used in Experiment 4 were the same as in Experiment 3.

Procedure and Design

The procedure and experimental design were the same as in Experiment 2b. That is, subjects were asked to rate their confidence in responding about the presence or absence of a target.

Results

The stimulus duration averaged about 129 to 183 msec, and block-by-block means are shown in Table 2.

The miss ('no' responses in target displays) and false-alarm ('yes' responses in feature displays and in conjunction displays) rates are shown in Table 10 and Figure 13. As in Experiment 3, the data analysis was performed in two steps to answer two questions: Were illusory conjunctions obtained in this task, and did confidence ratings of the real target percept and the illusory-conjunction based percept differ?

Illusory Conjunction Phenomenon

A three-way ANOVA was conducted on the false-alarm rates (%) of the feature and conjunction conditions. In this analysis, two levels of Display (feature and conjunction), three levels of Item Number (three, four, and five), and two levels of Filler (color filler and form filler) were the within-subject variables.

The main display-type effect was significant ($\underline{M}$=7.2% in the feature condition vs. 10.2% in the conjunction condition), $F(1,19)=7.771$, $\underline{p}<.05$. The main effect of Item Number was also significant ($\underline{M}$=8.5%, 7.8%, and 9.8% in 3 item, 4 item and 5 item displays), $F(2,38)=3.582$, $\underline{p}<.05$. As in Experiment 3, there was a significant interaction between the display type and the filler type, $F(1,19)=6.715$, $\underline{p}<.05$. Other main effects and interactions were not significant, all $\underline{p}>.4$.

Again, the false-alarm rate of the conjunction condition was higher than that of the feature condition, but only with the color filler. In other words, illusory conjunctions were obtained mostly in the color filler condition (5.5%) but not in the form filler condition (0.3%). As in Experiment 3, both the feature false-alarm rate and the conjunction false-alarm rate of the form-filler condition were not as high as the conjunction false-alarms in the color-filler condition ($\underline{M}$=7.9%, $\underline{M}$=8.3%, and 12.0% each), and illusory conjunctions in the color-filler condition resulted mainly from the increase in the

Table 10. Average Error Rates(%) for Target Displays, Feature Displays, and Conjunction Displays in Experiment 4.

Display Type	Number of Items			average
	three	four	five	
using 20 subjects				
(form filler)				
Miss in Target	2.8	4.3	2.8	3.3
FA in Feature	8.5	7.0	8.3	7.9
FA in Conjunction	8.0	7.8	9.0	8.3
means of FAs	8.3	7.4	8.6	
estimated IC	-0.5	0.8	0.7	0.3
(color filler)				
Miss in Target	5.0	6.3	10.8	7.4
FA in Feature	5.8	5.3	8.5	6.5
FA in Conjunction	11.5	11.0	13.5	12.0
means of FAs	8.7	8.2	11.0	
estimated IC	5.7	5.7	5.0	5.5
using 13 subjects+				
(form filler)				
Miss in Target	3.3	3.3	2.7	3.1
FA in Feature	8.7	7.3	7.7	7.9
FA in Conjunction	9.3	8.3	8.7	8.8
means of FAs	9.0	7.8	8.2	
estimated IC	0.6	1.0	1.0	0.9
(color filler)				
Miss in Target	4.7	4.7	10.3	6.6
FA in Feature	5.3	4.7	8.0	6.0
FA in Conjunction	12.0	12.3	16.3	13.5
means of FAs	8.7	8.5	12.2	
estimated IC	6.7	7.6	8.3	7.5

Abbreviations FA = false-alarm responses in feature displays and conjunction displays; Miss = miss responses in target displays; IC = illusory conjunction. The estimated amount of IC was computed by subtracting FA in feature displays from FA in conjunction displays.

+ The data from 13 subjects whose data were used for the analysis of confidence ratings (see the text).

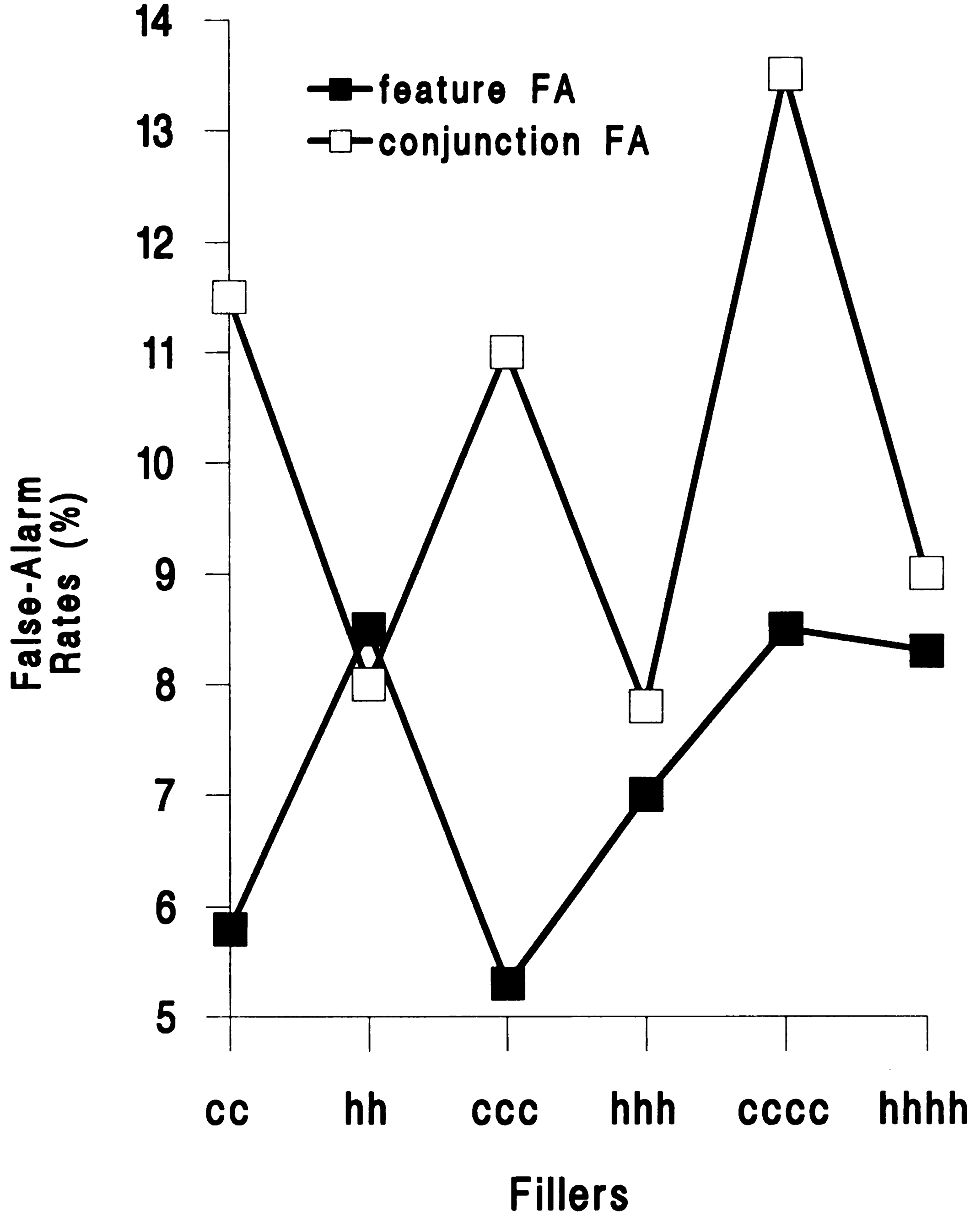

Figure 13. Average false-alarm rates of the feature condition and the conjunction condition as a function of filler type and display size in Experiment 4.

conjunction false-alarm rate, rather than the decrease in the feature false-alarm rate. The miss rate in the form-filler condition was lower than that in the color-filler condition (*M*=3.3%, and 7.4% each, $t(19)=4.343$, $p<.001$). This supports the interpretation that the failure to obtain illusory conjunctions in the form-filler condition is attributable to the unequal saliency of the color and form features as in Experiment 3.

<u>Confidence Ratings</u>

I used the same formula to estimate confidence ratings of the pure illusory conjunction component of the conjunction condition as in Experiment 2. As in previous experiments, I used data from only those subjects who showed more conjunction false-alarms than feature false-alarms because the occurrence of illusory conjunctions was prerequisite to examining the location-free view. Five subjects were discarded because of this criterion.

The confidence ratings of hit responses, of false-alarm responses in the feature condition, of false-alarm responses in the conjunction condition, and the estimated confidence rating of illusory conjunctions are shown in Table 11. I conducted t-tests between the average hit confidence rating and the estimated confidence rating of illusory conjunction responses, and between the estimated confidence ratings of illusory conjunction responses and feature false-alarms. The estimated confidence rating of illusory conjunction responses (*M*=3.87) was significantly lower than the hit

Table 11. <u>The Average Confidence Ratings of the Plus-sign in Target Displays, and the Average Confidence Ratings of the False Perception of a Plus-sign in Conjunction Displays, and in Feature Displays in Experiment 4.</u>

	confidence ratings
(A) real target in TD	4.93
(B) false target in CD (obtained)	3.48
(C) illusory conjunctions (estimated)	3.87
(D) false target in FD	2.70
t-test between (A) and (C)	$p<.005$
t-test between (D) and (C)	$p<.05$

<u>Abbreviations</u> TD=target displays; CD=conjunction displays; FD=feature displays; t-tests were conducted between the confidence rating of the real target perception in the target displays and that of the false perception of the target in the conjunction displays. 5 subjects were excluded because of zero or negative illusory conjunction rates.

confidence rating ($\underline{M}$=4.93), t(14)=3.402, $\underline{p}$<.005, and significantly higher than the feature false alarm confidence rating ($\underline{M}$=2.70), t(14)=2.204, $\underline{p}$<.05.

Discussion

Again subjects reported red horizontal lines (i.e., targets) more frequently in the displays containing red circles and white horizontal lines (i.e., conjunction displays) than in the displays containing only red circles without horizontal lines (i.e., feature displays). But subjects had lower confidence in these illusory percepts than in the percepts of the real target. This result is the same as the result obtained using intradimensional stimuli in Experiment 2. It is uncertain why Treisman and Schmidt (1982) failed to observe this difference in confidence in these two percepts. In fact, their Experiment 2 shows similar patterns to our Experiment 4. In Experiment 2, Treisman and Schmidt (1982) presented a probe before the stimulus display and asked subjects to report whether the probe matched any of the items in the following stimulus display. The probe was constructed by recombining a color and letter from the corresponding display (conjunction probe), by combining one feature from the display with another feature not present in that display (feature probe), or by matching exactly one of the items in the display (identical probe). They found that conjunction probes were considered as a target surely ('sure yes' response) in 15% of the trials, and less surely ('think yes') in 21% of the trials, while feature probes were considered as a target surely ('sure yes' response) in 7% of the trials, and less surely ('think yes') in 16% of the trials. In other words, conjunction false-alarms earned 'sure yes' responses in 42% of 'yes' responses, and 'think yes' responses in 58% of 'yes' responses, while feature false-alarms got 'sure yes' responses in 30% of 'yes' responses, and 'think yes' responses in 70% of 'yes' responses, which suggests that the percept based on illusory conjunctions is clearer than the percept based on random errors. However, it should be noticed that identical probes were reported with more certainty than conjunction probes ('sure yes' responses in 56% and 'think yes' responses in 44%). Therefore, it should not be concluded that the perceptual clarity of the percept based on illusory conjunctions is not different from that of the real percept, although the percept based on illusory conjunctions might be perceptually clearer than the percept based on the feature errors.

Summary of Experiments 3 and 4

In summarizing Experiments 3 and 4, the same data pattern of counting responses and confidence rating responses was obtained as in Experiments 1 and 2. In other words, although the target report rate was higher when the color red and horizontal lines were present than when the color red was present without horizontal lines, there was no hint of a reduction in the number of items perceived, and the estimated confidence rating of the false target percept was significantly lower than that of the real target percept. Therefore, even with the interdimensional stimuli I reach the same conclusion as using the intradimensional stimuli: The data are incompatible with the location-free view.

CHAPTER V: GENERAL DISCUSSION

Around 10 years ago Treisman and Paterson (1984; also Treisman & Schmidt, 1982) reported a finding that people sometimes perceived triangles from displays containing right angles (e.g., '∟') and tilted lines (e.g., '\'). They called this phenomenon an 'illusory conjunction'. The most surprising result was that the tendency to perceive illusory triangles was increased by the presence of circles. Treisman and Paterson (1984) concluded that the perception of illusory conjunctions was enhanced by the presence of circles because "closure could float free from circles and recombine with angles and lines" (p.26). My advisor (James L. Zacks) and I started a series of experiments intrigued by this explanation. If, as Treisman and Paterson (1984) propose, this false perception resulted from the false combination of a right angle, a tilted line, and the feature of closure contributed by a circle, what would a circle deficient of 'closure' look like? I referred to their explanation of illusory conjunctions as the 'location-free view' to emphasize its main assumption that visual feature codes lack location information.

Because it was hard to imagine circles deficient of closure, I speculated that although the presence of circles might sometimes increase the occurrence of the percept of an illusory triangle[17], circles retained the closure feature. Our next speculation was on the possibility that visual feature codes were originally contingent on their location (e.g., the feature of closure is contingent on the location of the circle to which it belongs), and that illusory conjunctions might result from other sources than this location-contingent feature representation.

I reviewed studies supporting my conjecture, mainly focusing on the close connection between features and their locations. I found that some theoretical and empirical studies seemingly supported this conjecture (Baylis & Driver, 1993; Johnston & Pashler, 1991; Kosslyn et al, 1991; Monheit & Johnston, 1994; Mozer, 1983; Nissen, 1985). Though conclusions were sometimes not consistent (e.g., Nissen, 1985, concluded that her data supported Treisman's 'feature integration theory', which argued that illusory conjunctions resulted from the false combination of features!), the consensus was that there was a good contingency between features and their location information.

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Of course, the presence of circles does not always increase the tendency to perceive illusory triangles. In fact, Treisman and Paterson (1984) reported that only 16 of 40 subjects showed sizable effects of the presence of circles on the illusory triangle perception. In our Experiments 1 and 2, the addition of an 'x' to displays did not increase the number of illusory conjunctions (i.e., plus-signs), though the 'x' contained another feature (i.e., 'intersection') of plus-signs.

In the face of these theoretical arguments and empirical data, I tried to reexamine Treisman and her colleagues' explanation of illusory conjunctions, and to test further this explanation by carrying out additional experiments on the relationship between features and their location. To this end I used a counting task or a confidence rating task in combination with the traditional illusory conjunction tasks.

Summary of Experiments 1a, 1b, 2a, 2b, 2c, 3, and 4

I adopted Prinzmetal (1981)'s task for obtaining illusory conjunctions. Using horizontal lines, vertical lines, and plus signs, Prinzmetal (1981) reported a significant rate of false perception of plus-signs (i.e., illusory conjunctions) from displays containing only horizontal and vertical lines.

If the false perception of plus signs resulted from the false combination of horizontal and vertical lines, as predicted by the location-free view, the total number of items perceived should be reduced by one. To test this prediction, I asked subjects to count items in displays after checking whether a plus-sign was present. In Experiments 1a, 1b, and 3, I obtained a significant number of illusory conjunctions, but there was no hint of undercounting by one caused by the false combination of features.

In Experiments 2a, 2b, 2c, and 4, I used a confidence rating task. I asked subjects to rate their confidence in their target search responses. The location-free view predicts that the confidence ratings for the real target and an illusory conjunction should not differ because the perceptual system does not distinguish the real target percept from the false percept of a target in the illusory conjunction condition. Contrary to this prediction, the confidence rating of the false percept of the target was significantly lower than that of the real target percept, though the former was higher than the confidence rating of the false percept resulting from random noise.

How can we explain the data obtained in this study? I obtained a significant number of illusory conjunctions, which implied that feature codes might be dissociable from their location codes. At the same time I observed that illusory conjunctions were not accompanied by a reduction in the number of items perceived, and that the percept resulting from illusory conjunction was not as clear as the percept resulting from a real stimulus. Does the visual representation contain location-free features as Feature-integration theory argues, or are feature codes in the visual representation closely connected and contingent on their location codes as other studies suggest (e.g., Johnston & Pashler, 1991)?

Theoretical Frameworks

I tried to search for theoretical frameworks in which location-contingent feature representation is a part of the framework, and to examine whether these models can explain counting and confidence rating data in addition to typical illusory conjunction data.

Only Location-Contingent Feature Representation

Several models assume that visual features are closely connected with their location (Baylis & Driver, 1993; Duncan & Humphreys, 1989; Johnston & Pashler, 1991; Mozer, 1983; Sagi & Julesz, 1985). Because the argument that visual features are always closely connected with their location is not compatible with illusory conjunction data[18] which have been replicated extensively, I will consider two models that could seemingly explain illusory conjunctions: Baylis and Driver (1993) and Mozer (1983). As will be clear, however, even these two models ultimately fail in explaining illusory conjunctions.

For example, Baylis and Driver (1993)[19] assume that visual features originally contain their location information and that these location-contingent feature codes

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With Virzi and Egeth (1984) some researchers tried to ascribe illusory conjunctions to postperceptual reporting difficulties (Johnston & Pashler, 1991) or to high level information processing (Humphreys & Bruce, 1989). But it should be noted, as they also recognized, that the existence of illusory conjunctions at the high or postperceptual level cannot exclude the possibility of the existence of illusory conjunctions at the perceptual level (see also Experiment 1).

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I thank J.M.Henderson for suggesting the possible relevance between Baylis and Driver (1983) and this study.

are analyzed in one subsystem of visual processing (i.e., the ventral, "what" system) to produce the description of relative positions of these features in each object. Separately from this ventral, "what" system, another subsystem of visual processing (i.e., the dorsal, "where" system) codes the relative location of objects within a scene. Therefore, it seems that shape information is analyzed separately from location information, which is similar to one of the main assumptions of Feature-Integration Theory. But this dissociation between shape information and location information occurs at the object level. In other words, if there are multiple objects in a display, the relative location information about these objects is processed in a different system (the dorsal, "where" system) from the system that processes the shape information (the ventral, "what" system). The location information and shape information of the parts of each object, however, are processed by the same system (ventral, "what" system), and the shape and location information of features are closely connected to produce the description of their relative positions in each object. Therefore, this model cannot explain why illusory conjunctions occur, nor why the final percept resulting from illusory conjunctions is less clear than the real target percept, although its prediction about counting data might be consistent with the counting data obtained in this study[20].

The second example of models assuming the contingency of features on their location was proposed by Mozer (1983)[21]. He examined the phenomenon called 'letter migration'. For example, when 'LINE' and 'LACE' are briefly presented, people sometimes report 'LANE'. This phenomenon of letter migration looks similar to the illusory conjunctions of features. Mozer wanted to find out whether this letter migration resulted from the interchange of two letters, or from copying a letter of one word onto a letter of the other word. In Experiment 2, he presented two words horizontally at each side of a center fixation, and asked subjects to report both words. As expected from previous studies, there were a significant number of letter migration errors. Most importantly, a majority of the migrations resulted from letters being copied from one word onto the other, rather than from the interchange between letters of the two words (10.71% in copying vs. 0.86% in interchange). In other words, given the words LICE and LANE, subjects were more likely to report LICE and LINE than LINE and LACE. Therefore, it is possible that illusory conjunctions result from this copying process.

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The counting of objects can be done correctly through the dorsal "where" system.

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I thank T.H.Carr for suggesting the possible relevance between Mozer (1983) and our study.

It should be noticed, however, that in Mozer (1983), one letter was replaced by another letter rather than being copied onto by another letter. In the example given above, 'A' in LANE was replaced by 'I'. If 'I' was copied on the existing letter 'A', subjects should have seen the overlapped letters of 'A' and 'I'. Therefore, this model can not explain the illusory conjunction data of this study where an item was added to another item rather than replacing the other item. If, as in Mozer (1985), subjects replaced a horizontal line with a vertical line, they should not have perceived an illusory plus-sign. Even when, as Mozer (1985) argued with his data, the false perception of a plus-sign resulted from copying (rather than replacing) a horizontal line or vertical line on one of the other vertical or horizontal lines, it is unclear how this model would explain our confidence rating data without an additional assumption that the perceptual clarity of the copied features is lower than that of the real features.

Representation containing both location-free and location-contingent feature representation.

Another theoretical framework implementing the feature-location contingency comes from Cohen and Ivry (1989). They examined the role of location codes in illusory conjunctions. In their Experiment 1, they presented a white digit at the fixation point and two colored letters at two locations on an imaginary circle around the centered digit. Subjects were asked to report the digit first, and then the two colored letters, and Cohen and Ivry (1989) manipulated the distance between the two letters. Cohen and Ivry (1989) found that illusory conjunctions between the two colored letters were formed only when these were adjacent.

In Experiment 4, in contrast, Cohen and Ivry (1989) presented two digits, one on each side of the fixation point. They added two colored letters inside or outside of the two digits. They also manipulated the distance between the two digits to control the size of the attentional spotlight. They found that inside the attentional span illusory conjunctions could occur between two letters regardless of the distance between them.

From these results, Cohen and Ivry (1989) concluded that when visual features are registered, coarse location information about these features may also be available to the perceptual system, but this information is available only when the features are presented outside the focus of attention. In contrast, all the features inside the focus of attention lack location information and are susceptible to false combination, and only location information of conjoined features is available.

Though this model can explain illusory conjunctions, it cannot explain the counting data obtained in this study. Suppose all of the items in a display (e.g., two horizontal lines and a vertical line) were inside the focus of attention. Subjects could perceive a plus because these features lack location information so that they are susceptible to false combination. In this case, the false perception of a plus will be accompanied by the reduction in the number of items perceived for the reason mentioned earlier. Suppose all of these items were outside the focus of attention. Subjects might report a plus because the location information of these features is only coarsely coded and because features could not be combined without the help of attention. In this case it is uncertain how subjects can count objects anyway without features integrated into objects. If subjects consider each feature as an object, the false perception of a plus will again be accompanied by the reduction in the number of objects perceived.

In addition to those difficulties, it is uncertain how this model can explain the low confidence ratings in illusorily formed percepts, and how illusory conjunctions could occur at different levels (see Treisman & Schmidt, 1982 for the feature level, Treisman & Souther, 1986 for the letter level, Prinzmetal, Treiman, & Rho, 1986 for the syllable level, and Virzi & Egeth, 1984 for the concept level).

Dual Code View of Location-contingent and Location-free Visual Representations

Since illusory conjunctions are an established phenomenon, the data implying a contingency between visual features and their location tags tempts us simply to hypothesize that both location-free feature codes and location-contingent feature codes might be available in the visual recognition processes. I call this alternative a 'dual code view'. As seen earlier, theoretical frameworks postulating only one type of feature representation cannot explain either illusory conjunctions or the counting data observed in these experiments (see Figure 14a).

This dual code view, of course, should explain at least the following four points. First, it should explain the existence of illusory conjunctions. Second, it should explain the counting data observed in this study, which imply that features are closely attached to their locations. Third, it should explain why the perceptual clarity of the illusorily formed percept is lower than that of the real percept. Fourth, it should explain how illusory conjunctions might occur at different levels.

Assumptions

I make several assumptions in proposing the dual code view, which are represented schematically in Figure 14b. First, I assume that when we see a visual input, it is analyzed and coded into visual feature codes associated with specific locations (a). This location-contingent feature representation forms a final percept (b). Second, I assume that for some reason the visual system forms another visual representation using a subset of the location-contingent feature representation (c). In this feature representation, feature codes are either loosely connected with or lack entirely location information.

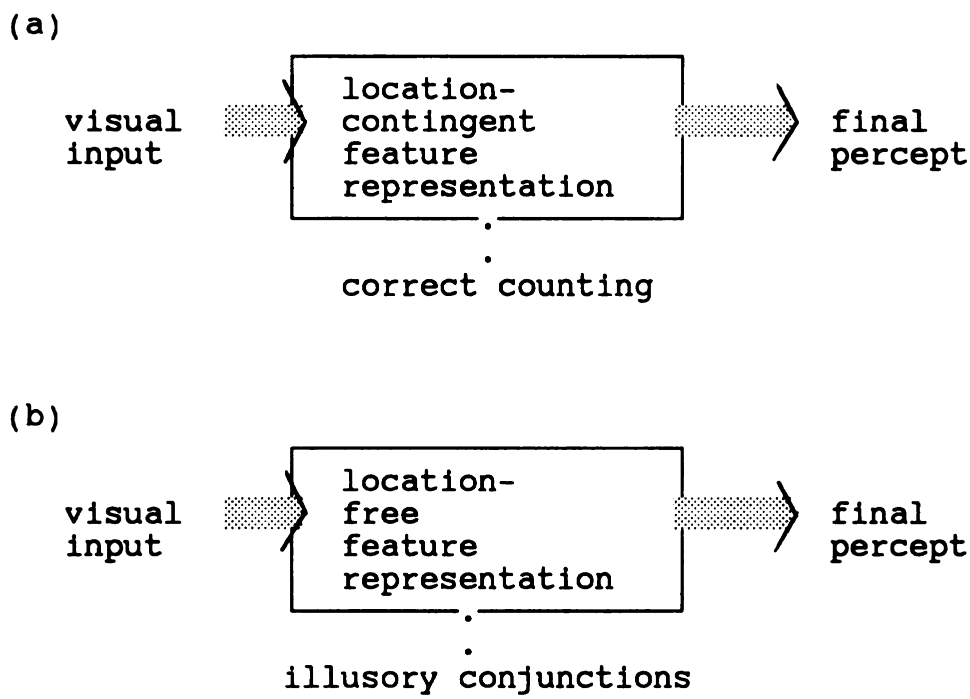

Figure 14a. Views postulating only location-contingent feature representation or only location-free feature representation. (a) Location-Contingent Feature View: It assumes that visual features are contingent on location information and predicts that objects are correctly counted, but it cannot explain why illusory conjunctions are experienced. (b) Location-Free Feature View: It assumes that feature codes lack their location information and are susceptible to false combination (i.e., illusory conjunctions), but it cannot explain why illusory conjunctions are not accompanied by a reduction in the number of objects perceived.

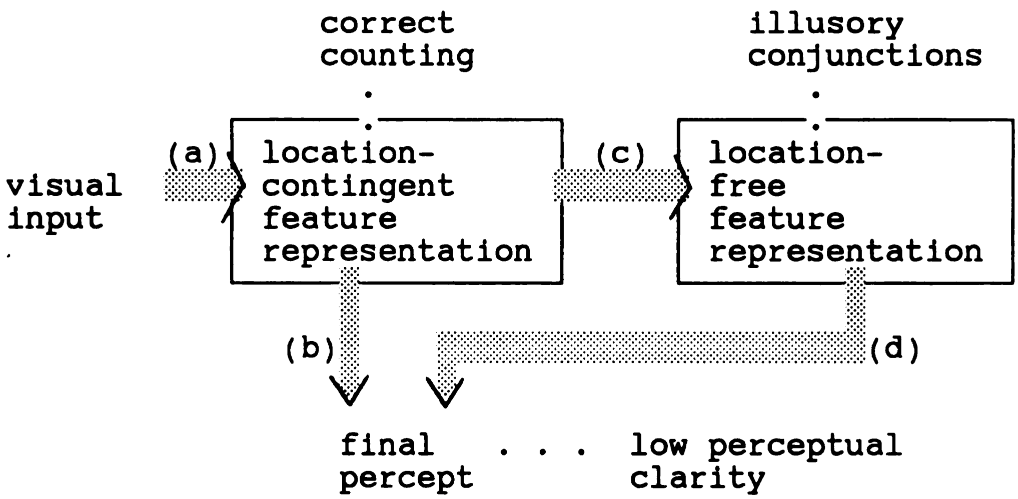

Figure 14b. Dual Code View: This view assumes that both location-contingent and location-free feature representations are available to the final percept. It predicts that illusory conjunctions are sometimes experienced and can explain why illusory conjunctions are not accompanied by the reduction in the number of objects (see the text).

The second location-free feature representation is also used in making the final percept by providing additional properties to the final percept (d). In other words, two types of feature representations contribute to the formation of the final percept, emphasizing different aspects of the visual input[22].

Because features in the location-free representation lack location information, they are susceptible to false combinations[23]. This falsely combined feature representation

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Though it seems not to be plausible that two different visual representations are reflected in a single final percept, we can find one example in our everyday visual experience. Suppose we see a person in the distance and compare him/her with another nearby person. We do not perceive the distant person to be smaller than the nearby person, although their retinal image sizes are very different (size constancy). But we also get the visual impression that the distant person looks smaller than the nearby person nevertheless. These two impressions are both reflected in our final percept without any confusion. The former visual impression reflects the actual size of two persons, while the latter visual impression reflects the retinal size of two persons. In the same way, location-contingent feature representation and location-free feature representation could be reflected in our final percept and be accessible consciously. The existence of a location-contingent feature representation and location-free feature representation is also implied by neurophysiological data. Some visual area mainly contain visual feature selective cells responding to relatively wide areas of the visual input (Desimone & Ungerleider, 1989), whereas other cells in other visual areas are sensitive only to the visual input presented in quite a restricted part of the visual field (Tootell, Silverman, Switkes,& DeValois, 1982). Furthermore, Zeki (1993) recently suggested the possibility that all of these visual areas participate in forming the final visual percept, a suggestion similar to our dual code view.

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Several studies showed that many factors might govern this false combination of features, such as Gestalt principles (Prinzmetal, 1981), linguistic constraints (Prinzmetal, is usually prevented from being reflected in the final percept by the location-contingent representation. Nevertheless, if the falsely combined feature representation sometimes succeeds in being reflected in the final percept, illusory conjunctions may be experienced with less perceptual clarity because of the conflicts between the two feature types of representations.

As is self-evident, this dual code view can explain the data obtained in this study as well as typical illusory conjunctions. That is, we can sometimes experience illusory conjunctions from the visual representation produced by the location-free feature representation. But even when illusory conjunctions are experienced, the location-contingent feature representation produces another visual representation where visual features are closely connected with their location so that correct counting is guaranteed. The conflict between the two visual representations not only prevents the occurrence of illusory conjunctions, but once illusory conjunctions occur, it reduces their clarity in the final percept. That is why the incidence of illusory conjunctions is not as high as expected even under conditions where focal, serial attention is interrupted, and also why the confidence ratings of illusory conjunctions are

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(continued from the previous footnote)
Treiman, & Rho, 1986), and meaning constraints (Virzi & Egeth, 1984). It should be examined, however, in further studies when and which visual features are more likely to be falsely combined.

lower than those of the veridical percept. The binding problem of the separate visual features is basically solved because visual features are combined through their shared locations.

This dual code view is diagrammed in Figure 14b.

Speculations on location-free visual feature representation

My conjecture about the dual code view should be examined in further studies and I have no compelling reason why the location-free feature representation is formed if there is already a location-contingent representation, nor do I know what these location-free feature codes are, and how this representation is formed.

Several computational models offer possible candidates for these location-free visual feature codes. For example, Marr and Nishihara (1978; see also Biederman, 1986) proposed that volummetric primitives (or geons in Biederman, 1986), which apparently have no location constraints, were extracted from the location-contingent primal sketch or $2^1/_2$D sketch to produce an object-centered visual representation. Similarly, other researchers proposed that other invariant features (Lowe, 1987), or trigger features (Kosslyn et al, 1990) might be extracted from the visual representation to obtain perceptual constancy. These representations could be candidates for the location-free feature representation of the dual code view.

At this point, I do not restrict the candidates for the location-free feature codes to simple visual features, nor to visual features in a spatially delimited area. It is possible that each line of the letter 'F' or the whole letter 'F' could be represented by individual location-free features. Thus features at apparently different levels could produce illusory conjunctions (Prinzmetal, Treiman,& Rho, 1986; Treisman & Schmidt, 1982 and Treisman & Souther, 1986; Virzi & Egeth, 1984).

Comparisons with Cohen and Ivry (1989)

As mentioned earlier, Cohen and Ivry (1989) also proposed that there are two types of feature representation: feature representation with coarse location information and location-free feature representation. The dual code view shares some characteristics of Cohen and Ivry's (1989) model. As Cohen and Ivry (1989) propose, this view also assumes that the initial feature representation contains location information; some features of the feature representation are extracted to form location-free feature codes; and location-contingent feature codes as well as location-free feature codes exist and are reflected in the final percept.

However, there are also critical differences between my view and Cohen and Ivry (1989). I assume that the formation of the location-free visual representation is object-based rather than space-based. Second, I assume that location-contingent feature codes and location-free feature codes exist in separate representations rather than in the same representation. Cohen and Ivry (1989) assume that the visual features in the focal attentional beam are transformed to location-free features, while I assume that the formation of the location-free feature codes is in addition to the existing location-contingent feature codes. I also assume that these two types of feature codes might sometimes conflict when a single part of the visual input produces two different, incompatible feature representations as in illusory conjunctions.

Final Comments on This Research

I hope that this research contributes to the understanding of our visual perception in several ways. First, this research showed that the visual representation producing illusory conjunctions is not the only visual representation contributing to the formation of the final percept. Clearly, we could count the items in displays correctly even though the number of items perceived should be reduced if illusory conjunctions result from the false combination of separate features. This study also showed the possibility that both location-contingent and location-free visual images are available and represented in the final percept. Two visual impressions are reflected in subjects' performance even when these are incompatible (e.g., illusory conjunctions and correct counting). Second, this study showed that an illusorily formed percept might be different from a percept based on a veridical input at least in perceptual clarity.

But one point should be considered about the differences between Treisman and Schmidt (1982) and Experiments 1 and 2 of this research. As mentioned earlier, Treisman and Schmidt (1982) used mainly dual tasks to prevent focal attention, while I used brief presentations. Therefore, I am not sure whether the same patterns of counting and confidence rating data might be obtained in Treisman and Schmidt's (1982) task. Subjects in Treisman and Schmidt (1982) had to report two side digits first, so the stimulus set is more likely to be included within the attentional beam if two digits are located outside the stimuli to be reported (e.g., Treisman & Schmidt, 1982), than if the duration of the stimulus display is simply reduced (e.g., Prinzmetal, 1981; Treisman & Paterson, 1984; the current study).

If features inside the attentional beam lose all their location information (Cohen & Ivry, 1989), the reduction of items perceived is expected in this task. This possibility is worth examining in future studies.

APPENDICES

APPENDIX A

Approval Letter from University Committee on Research Involving Human Subjects

MICHIGAN STATE UNIVERSITY

OFFICE OF VICE PRESIDENT FOR RESEARCH
AND DEAN OF THE GRADUATE SCHOOL

EAST LANSING • MICHIGAN • 48824-1046

March 5, 1993

TO: Dr. James Zacks
236 Psychology Research Building

RE:	IRB #:	88-522
	TITLE:	VISUAL PROCESSING OF FEATURES AND OBJECTS IN AGING
	REVISION REQUESTED:	N/A
	CATEGORY:	Full Review
	APPROVAL DATE:	03/01/1993

The University Committee on Research Involving Human Subjects' (UCRIHS) review of this project is complete. I am pleased to advise that the rights and welfare of the human subjects appear to be adequately protected and methods to obtain informed consent are appropriate. Therefore, the UCRIHS approved this project including any revision listed above.

UCRIHS approval is valid for one calendar year, beginning with the approval date shown above. Investigators planning to continue a project beyond one year must seek updated certification. Request for renewed approval must be accompanied by all four of the following mandatory assurances.

1. The human subjects protocol is the same as in previous studies.
2. There have been no ill effects suffered by the subjects due to their participation in the study.
3. There have been no complaints by the subjects or their representatives related to their participation in the study.
4. There has not been a change in the research environment nor new information which would indicate greater risk to human subjects than that assumed when the protocol was initially reviewed and approved.

There is a maximum of four such expedited renewals possible. Investigators wishing to continue a project beyond that time need to submit it again for complete review.

UCRIHS must review any changes in procedures involving human subjects, prior to initiation of the change. Investigators must notify UCRIHS promptly of any problems (unexpected side effects, complaints, etc.) involving human subjects during the course of the work.

If we can be of any future help, please do not hesitate to contact us at (517) 355-2180 or FAX (517) 336-1171.

Sincerely,

David E. Wright, Ph.D.
UCRIHS Chair

DEW:pjm

MICHIGAN STATE
UNIVERSITY

March 21, 1994

TO: Dr. James L. Zacks
236 Psychology Research Building

RE:	IRB #:	88-522
	TITLE:	VISUAL PROCESSING OF FEATURES AND OBJECTS IN AGING
	REVISION REQUESTED:	03/10/1994
	CATEGORY:	Full Review
	APPROVAL DATE:	03/12/1994

The University Committee on Research Involving Human Subjects' (UCRIHS) review of this project is complete. I am pleased to advise that the rights and welfare of the human subjects appear to be adequately protected and methods to obtain informed consent are appropriate. Therefore, the UCRIHS approved this project including the revision listed above.

Renewal: **UCRIHS approval is valid for one calendar year, beginning with the approval date shown above.** Investigators planning to continue a project beyond one year must use the green renewal form (enclosed with the original approval letter or when a project is renewed) to seek updated certification. There is a maximum of four such expedited renewals possible. Investigators wishing to continue a project beyond that time need to submit it again for complete review.

Revisions: UCRIHS must review any changes in procedures involving human subjects, prior to initiation of the change. If this is done at the time of renewal, please use the green renewal form. To revise an approved protocol at any other time during the year, send your written request to the UCRIHS Chair, requesting revised approval and referencing the project's IRB # and title. Include in your request a description of the change and any revised instruments, consent forms or advertisements that are applicable.

Problems/ Changes: Should either of the following arise during the course of the work, investigators must notify UCRIHS promptly: (1) problems (unexpected side effects, complaints, etc.) involving human subjects or (2) changes in the research environment or new information indicating greater risk to the human subjects than existed when the protocol was previously reviewed and approved.

If we can be of any future help, please do not hesitate to contact us at (517) 355-2180 or FAX (517) 336-1171.

Sincerely,

David E. Wright, Ph.D.
UCRIHS Chair

DEW:pjm

OFFICE OF
RESEARCH AND GRADUATE STUDIES
University Committee on Research Involving Human Subjects (UCRIHS)
Michigan State University
225 Administration Building
East Lansing, Michigan
48824-1046
517/355-2180
FAX: 517/336-1171

APPENDIX B

The Individual Data of Obtained Counting Response Patterns, and Predictions of the Location-Free View and Control

a) four item displays of Experiment 1a

Subjects	obtained			location-free view			control*		
	3	4	5	3	4	5	3	4	5
S1	19.0	76.2	4.8	77.7	22.3	0.0	17.2	82.8	0.0
S2	0.0	100.0	0.0	56.7	40.0	3.3	0.0	96.7	3.3
S3	12.5	50.0	37.5	11.1	69.4	19.4	2.4	63.1	34.5
S4	0.0	100.0	0.0	97.4	2.6	0.0	2.5	87.5	10.0
S5	37.5	37.5	25.0	60.0	6.7	33.3	15.8	49.1	35.1
S6	15.4	69.2	15.4	41.8	32.4	25.7	8.8	59.2	31.4
S7	0.0	71.4	28.6	49.0	51.0	0.0	11.4	78.8	9.8
S8	0.0	86.4	13.6	69.0	31.0	0.0	14.0	81.2	4.9
S9	13.0	82.6	4.3	73.3	24.5	2.1	19.8	65.2	15.0
S10	20.0	71.4	8.6	50.9	47.5	1.6	16.3	78.8	4.9
S11	20.0	40.0	40.0	64.6	33.3	2.1	4.3	82.9	12.8
S12	25.0	65.0	10.0	47.3	51.3	1.4	17.4	81.2	1.4
S13	0.0	85.7	14.3	75.7	18.7	5.5	3.9	86.7	9.4
S14	25.0	62.5	12.5	60.4	37.5	1.9	24.8	70.0	5.3
S15	0.0	80.0	20.0	59.1	39.5	1.3	18.4	81.6	0.0
S16	0.0	100.0	0.0	32.1	41.7	26.3	5.1	69.9	25.0
S17	44.4	55.6	0.0	50.0	29.6	20.4	20.1	48.9	30.9
S18	50.0	50.0	0.0	38.6	52.9	8.6	7.5	77.8	14.7
S19	0.0	100.0	0.0	88.7	11.3	0.0	7.2	92.8	0.0
S20	0.0	100.0	0.0	58.3	30.6	11.1	9.0	74.5	16.5
S21	0.0	90.0	10.0	46.9	42.5	10.6	0.0	86.3	13.8
S22	25.0	75.0	0.0	70.9	29.1	0.0	2.7	94.5	2.7
S23	0.0	100.0	0.0	96.3	3.8	0.0	0.0	98.7	1.3
S24	0.0	87.5	12.5	68.7	27.0	4.3	0.9	93.9	5.2
S25	25.0	75.0	0.0	45.1	26.4	28.6	4.8	60.2	35.0
S26	42.9	42.9	14.3	61.0	37.2	1.8	10.6	86.7	2.7
S27	0.0	100.0	0.0	80.0	20.0	0.0	11.4	87.3	1.3
S28	38.5	53.8	7.7	30.6	51.1	18.2	13.9	64.7	21.4
S29	22.2	66.7	11.1	60.0	38.1	1.9	13.1	78.4	8.4
AVRG	13.5	74.6	11.9	59.4	32.7	7.9	9.8	77.9	12.3

* "Control" means the data patterns expected if there were no reduction in the number of items perceived when illusory conjunctions were experienced.

b) five item displays of Experiment 1a

Subjects	obtained			location-free view			control		
	3	4	5	3	4	5	3	4	5
S1	0.0	38.1	61.9	25.2	74.8	0.0	10.2	40.3	49.5
S2	0.0	0.0	100.0	0.0	76.0	24.0	4.0	16.0	80.0
S3	5.3	63.2	31.6	2.5	47.6	49.9	3.5	25.0	71.5
S4	0.0	20.0	80.0	1.8	91.1	7.1	1.8	39.3	58.9
S5	0.0	0.0	100.0	11.8	36.8	51.3	2.7	12.2	85.1
S6	0.0	56.3	43.8	11.4	52.6	36.0	8.9	42.2	48.9
S7	0.0	33.3	66.7	12.4	61.5	26.0	0.0	33.6	66.4
S8	3.1	6.3	90.6	8.0	59.2	32.8	3.2	19.2	77.6
S9	5.0	35.0	60.0	14.7	63.5	21.7	0.0	38.9	61.1
S10	5.6	52.8	41.7	15.9	55.2	28.9	6.4	56.8	36.9
S11	0.0	25.0	75.0	4.1	68.6	27.3	2.1	21.4	76.5
S12	5.9	41.2	52.9	17.4	72.2	10.3	16.2	51.9	31.9
S13	0.0	50.0	50.0	3.8	73.8	22.5	0.0	19.4	80.6
S14	10.0	30.0	60.0	15.1	57.2	27.7	13.2	36.1	50.7
S15	0.0	27.2	72.7	9.2	65.8	25.0	4.6	30.7	64.7
S16	0.0	50.0	50.0	10.3	89.7	0.0	5.0	22.5	72.5
S17	0.0	10.0	90.0	10.0	49.4	40.5	0.0	28.0	72.0
S18	0.0	0.0	100.0	7.5	70.7	21.8	1.5	59.3	39.2
S19	20.0	70.0	10.0	6.2	85.8	8.0	0.0	48.9	51.1
S20	0.0	100.0	0.0	11.6	81.5	6.9	13.2	56.0	30.8
S21	0.0	11.8	88.2	0.0	68.4	31.6	0.0	13.1	86.9
S22	0.0	9.1	90.9	2.3	62.1	35.6	0.0	14.2	85.8
S23	0.0	0.0	100.0	0.0	98.7	1.3	0.0	2.6	97.4
S24	0.0	10.0	90.0	0.7	63.2	36.0	0.8	10.5	88.8
S25	0.0	60.0	40.0	5.3	50.2	44.5	0.0	14.2	85.8
S26	0.0	50.0	50.0	15.9	48.8	35.2	9.0	15.9	75.1
S27	0.0	0.0	100.0	11.4	87.3	1.3	2.5	21.3	76.3
S28	15.4	61.5	23.1	12.1	60.2	27.7	6.4	47.3	46.3
S29	0.0	50.0	50.0	10.9	75.8	13.3	4.9	51.8	43.3
AVRG	2.4	33.1	64.5	8.9	67.2	23.9	4.1	30.6	65.2

c) four item displays of Experiment 1b

Subjects	obtained			location-free view			control		
	3	4	5	3	4	5	3	4	5
(X-present)									
S1	25.0	75.0	0.0	71.1	28.9	0.0	23.5	71.8	4.7
S2	10.0	80.0	10.0	56.3	43.8	0.0	13.2	86.8	0.0
S3	28.6	71.4	0.0	10.4	89.6	0.0	15.6	84.4	0.0
S4	0.0	66.7	33.3	46.9	44.8	8.5	12.5	72.9	14.6
S5	0.0	100.0	0.0	62.5	37.5	0.0	26.7	73.3	0.0
S6	50.0	50.0	0.0	72.1	27.9	0.0	29.3	66.7	4.0
S7	12.5	87.5	0.0	69.2	30.8	0.0	28.2	71.8	0.0
S8	20.0	40.0	40.0	52.1	19.4	28.5	9.4	50.0	40.6
S9	0.0	75.0	25.0	57.1	22.9	20.0	18.5	55.4	26.2
S10	0.0	100.0	0.0	80.2	19.8	0.0	30.6	64.6	4.9
S11	16.7	83.3	0.0	87.5	12.5	0.0	29.2	70.8	0.0
S12	20.0	60.0	20.0	78.7	21.3	0.0	27.8	67.6	4.6
S13	20.0	80.0	0.0	64.8	35.2	0.0	4.4	86.8	8.8
AVRG	15.6	74.5	9.9	62.2	33.4	4.4	20.7	71.0	8.3
(X-absent)									
S1	8.3	50.0	41.7	34.7	46.3	18.9	0.0	74.7	25.3
S2	0.0	60.0	40.0	6.6	51.3	42.1	7.4	58.1	34.6
S3	0.0	80.0	20.0	49.7	50.3	0.0	2.8	88.9	8.3
S4	0.0	100.0	0.0	14.8	85.2	0.0	14.8	85.2	0.0
S5	0.0	100.0	0.0	62.7	26.1	11.1	3.5	74.9	21.6
S6	66.7	33.3	0.0	40.0	60.0	0.0	23.1	76.9	0.0
S7	0.0	100.0	0.0	35.1	39.2	25.7	3.5	70.7	25.7
S8	11.1	55.6	33.3	25.9	68.8	5.3	41.8	47.6	10.6
S9	16.7	16.7	66.7	29.6	33.3	37.0	11.1	44.4	44.4
S10	0.0	77.8	22.2	40.0	53.8	6.3	17.5	73.4	9.1
S11	0.0	75.0	25.0	33.3	36.5	30.2	14.3	62.4	23.3
S12	0.0	0.0	100.0	9.2	27.7	63.1	4.0	28.0	68.0
S13	0.0	100.0	0.0	27.8	67.6	4.6	14.7	70.6	14.7
S14	9.1	90.9	0.0	75.2	24.8	0.0	24.9	75.1	0.0
S15	0.0	12.5	87.5	0.0	27.0	73.0	0.0	10.0	90.0
AVRG	7.5	63.4	29.1	33.2	47.7	19.1	12.8	64.8	22.4

d) five item displays of Experiment 1b

Subjects	obtained			location-free view			control		
	3	4	5	3	4	5	3	4	5
(X-present)									
S1	0.0	33.3	66.7	29.4	64.7	5.9	12.5	56.3	31.3
S2	0.0	9.1	90.9	15.4	71.2	13.3	0.0	29.6	70.4
S3	16.7	83.3	0.0	18.3	81.7	0.0	18.3	81.7	0.0
S4	0.0	28.6	71.4	15.9	39.8	44.3	8.5	17.0	74.5
S5	14.3	57.1	28.6	40.0	60.0	0.0	27.3	54.5	18.2
S6	0.0	100.0	0.0	19.4	76.7	3.9	14.0	81.3	4.7
S7	0.0	60.0	40.0	20.8	66.7	12.5	7.4	65.4	27.2
S8	0.0	0.0	100.0	10.0	40.0	50.0	0.0	23.5	76.5
S9	16.7	50.0	33.3	21.7	46.9	31.5	13.3	46.9	39.9
S10	0.0	100.0	0.0	15.9	61.9	22.2	22.3	46.8	30.9
S11	0.0	50.0	50.0	16.7	70.8	12.5	4.4	52.2	43.4
S12	0.0	87.5	12.5	22.2	74.1	3.7	0.0	70.4	29.6
S13	0.0	22.2	77.8	3.9	71.5	24.6	0.0	32.0	68.0
AVRG	3.6	52.4	43.9	19.2	63.5	17.3	9.8	50.6	39.6
(X-absent)									
S1	0.0	28.6	71.4	0.0	61.2	38.8	0.0	34.2	65.8
S2	0.0	33.3	66.7	6.4	47.1	46.5	0.0	43.9	56.1
S3	7.1	35.7	57.1	3.3	58.1	38.6	0.0	25.8	74.2
S4	16.7	83.3	0.0	16.7	83.3	0.0	0.0	5.0	95.0
S5	0.0	0.0	100.0	3.2	64.0	32.8	3.2	34.8	61.9
S6	33.3	33.3	33.3	53.8	46.2	0.0	34.4	51.6	14.1
S7	0.0	90.0	10.0	4.4	91.2	4.4	12.5	75.0	12.5
S8	0.0	72.7	27.3	32.4	56.9	10.8	11.5	54.2	34.4
S9	0.0	50.0	50.0	11.1	50.0	38.9	12.5	41.7	45.8
S10	0.0	42.9	57.1	21.8	75.0	3.2	15.8	67.5	16.7
S11	50.0	25.0	25.0	0.0	72.8	27.2	0.0	34.4	65.6
S12	0.0	50.0	50.0	5.3	37.3	57.3	0.0	28.6	71.4
S13	0.0	75.0	25.0	10.1	79.8	10.1	0.0	75.5	24.5
S14	0.0	50.0	50.0	23.5	76.5	0.0	8.0	76.0	16.0
S15	0.0	33.3	66.7	0.0	27.0	73.0	0.0	10.0	90.0
AVRG	7.1	46.9	46.0	12.8	61.8	25.4	6.8	50.4	42.9

e) four item displays of Experiment 3

Subjects	obtained			location-free view			control		
	3	4	5	3	4	5	3	4	5
S1	0.0	100.0	0.0	56.3	18.8	25.0	3.9	59.2	36.8
S2	0.0	0.0	100.0	31.6	42.1	26.3	0.0	45.0	55.0
S3	75.0	25.0	0.0	90.0	10.0	0.0	0.0	94.7	5.3
S4	0.0	60.0	40.0	60.0	35.0	5.0	0.0	63.2	36.8
S5	25.0	75.0	0.0	64.0	36.0	0.0	0.0	80.0	20.0
S6	0.0	100.0	0.0	34.4	65.6	0.0	8.3	91.7	0.0
S7	0.0	100.0	0.0	78.9	15.8	5.3	10.5	84.2	5.3
S8	0.0	50.0	50.0	25.0	35.0	40.0	16.7	38.9	44.4
S9	0.0	60.0	40.0	45.8	37.5	16.7	25.0	41.7	33.3
S10	0.0	100.0	0.0	82.4	17.6	0.0	0.0	100.0	0.0
S11	0.0	100.0	0.0	52.6	31.6	15.8	0.0	84.2	15.8
S12	33.3	33.3	33.3	30.6	69.4	0.0	10.5	86.8	2.6
S13	50.0	50.0	0.0	76.5	23.5	0.0	8.3	58.3	33.3
AVRG	14.1	65.6	20.3	56.0	33.7	10.3	6.4	71.4	22.2

f) five item displays of Experiment 3

Subjects	obtained			location-free view			control		
	3	4	5	3	4	5	3	4	5
S1	0.0	100.0	0.0	5.3	78.9	15.8	0.0	15.0	85.0
S2	0.0	0.0	100.0	0.0	45.0	55.0	5.0	25.0	70.0
S3	0.0	100.0	0.0	0.0	94.7	5.3	0.0	18.8	81.3
S4	0.0	0.0	100.0	0.0	63.2	36.8	0.0	0.0	100.0
S5	0.0	50.0	50.0	0.0	50.0	50.0	0.0	4.2	95.8
S6	40.0	60.0	0.0	26.2	73.8	0.0	25.6	36.8	37.6
S7	0.0	50.0	50.0	28.4	67.4	4.2	20.0	8.4	71.6
S8	0.0	40.0	60.0	13.9	32.4	53.7	4.2	25.0	70.8
S9	0.0	0.0	100.0	10.0	50.0	40.0	5.6	22.2	72.2
S10	0.0	100.0	0.0	0.0	100.0	0.0	6.2	18.8	75.0
S11	0.0	0.0	100.0	0.0	84.2	15.8	0.0	25.0	75.0
S12	50.0	0.0	50.0	10.5	61.8	27.6	10.0	50.0	40.0
S13	0.0	0.0	100.0	5.6	38.9	55.6	0.0	23.8	76.2
AVRG	6.9	38.4	54.6	7.7	64.6	27.7	5.9	21.0	73.1

APPENDIX C

An Alternative Analysis of Counting Response Patterns

I also examined the counting response patterns predicted by the location-free view in Experiments 1a, 1b and 3 using a logic different from that described in the text. The logic is as follows: If subjects counted five items in a non-illusory conjunction displays, the predicted count will be four in the illusory conjunction version of the display. Likewise, if subjects counted four items in a non-illusory conjunction displays, the predicted count will be three in the illusory conjunction version. Finally, if subjects counted three items in a non-illusory conjunction displays, the predicted count will also be three in the illusory conjunction version of the display, because a count of two was not allowed. Responses of five, four, and three for non-illusory conjunction displays were calculated by averaging counting response patterns across hits and misses in target displays, false-alarms and correct-rejects in feature displays, and correct-rejects in conjunction displays, in all of which subjects did not experience illusory conjunctions.

Because false-alarm responses in conjunction displays resulted from random noise as well as illusory conjunctions of features (Treisman & Schmidt, 1982), we decomposed conjunction false-alarm responses into two portions. The proportion of false-alarm response in the illusory conjunction condition which were pure illusory conjunctions was calculated by the formula,

$$IC_{prop} = (FA_{conjunction} - FA_{feature})/FA_{conjunction},$$

where IC_{prop} is the proportion of pure illusory conjunctions in conjunction false-alarm responses, and $FA_{conjunction}$ and $FA_{feature}$ are the error rates of conjunction displays and of feature displays.

Therefore, the counting response patterns of conjunction false-alarms predicted by the location-free view can be estimated by the formulae,

$$\text{Counting } 5_{predicted} = \text{Counting } 5_{non\_ic} * (1-IC_{prop}),$$

$$\text{Counting } 4_{predicted} = \text{Counting } 4_{non\_ic} * (1-IC_{prop}) + IC_{prop} * \text{Counting } 5_{non\_ic},$$

$$\text{Counting } 3_{predicted} = \text{Counting } 3_{non\_ic} * (1-IC_{prop}) + IC_{prop} * (\text{Counting } 4_{non\_ic} + \text{Counting } 3_{non\_ic}),$$

where Counting $5_{predicted}$, Counting $4_{predicted}$, and Counting $3_{predicted}$ are counting response patterns of conjunction false-alarms predicted by the location-free view, Counting 5_{non_ic}, Counting 5_{non_ic}, and Counting 5_{non_ic} are average counting response patterns of non-illusory conjunction responses.

This logic and procedure was applied to 3-, 4-, and 5-item displays in succession. The results are shown in Table

12. Again significant deviations were found between obtained counting data patterns and counting data patterns predicted by the location-free view.

Table 12. 95% Confidence Intervals of Obtained Conjunction False-Alarm Counting Response Patterns, and the Prediction of the Location-Free View in Experiment 1a, 1b, and 3.

stimuli	Counting Responses		
	3 items	4 items	5 items
Experiment 1a			
3 items			
obtained data			
obtained	66.9	27.3	5.8
upper-limit	84.3	35.7	9.7
lower-limit	49.5	18.8	2.0
predicted data			
location-free	83.7	14.0*	2.2
4 items			
obtained data			
obtained	13.5	74.6	11.9
upper-limit	19.1	82.1	17.0
lower-limit	7.9	67.1	6.8
predicted data			
location-free	60.1*	35.4*	4.6*
5 items			
obtained data			
obtained	2.4	33.1	64.5
upper-limit	4.2	42.6	74.8
lower-limit	0.6	23.6	54.2
predicted data			
location-free	27.2*	50.5*	22.5*

(continued from the previous page)

stimuli	Counting Responses		
	3 items	4 items	5 items
Exp 1b (x-displays)			
3 items			
obtained data			
obtained	63.4	29.3	7.3
upper-limit	84.0	44.7	15.9
lower-limit	42.8	13.9	0.0
predicted data			
location-free	88.4*	10.2*	1.4
4 items			
obtained data			
obtained	15.6	74.5	9.9
upper-limit	23.5	84.0	17.9
lower-limit	7.7	65.0	1.9
predicted data			
location-free	63.1*	33.2*	3.8
5 items			
obtained data			
obtained	3.7	52.4	43.9
upper-limit	7.5	70.5	63.1
lower-limit	0.0	34.3	24.7
predicted data			
location-free	41.1*	45.4	13.5*
Exp 1b (no-x-displays)			
3 items			
obtained data			
obtained	42.8	37.1	20.1
upper-limit	64.8	47.3	29.6
lower-limit	20.8	26.9	10.6
predicted data			
location-free	68.8*	24.8*	6.5*
4 items			
obtained data			
obtained	7.5	63.4	29.1
upper-limit	16.2	80.9	45.9
lower-limit	0.0	45.9	12.3
predicted data			
location-free	49.0*	40.2*	10.8*
5 items			
obtained data			
obtained	7.1	46.9	46.0
upper-limit	14.7	59.3	59.2
lower-limit	0.0	34.5	32.8
predicted data			
location-free	35.1*	47.9	17.0*

(continued from the previous page)

	counting responses		
	three	four	five
Experiment 3			
3 items			
Obtained Data			
obtained data	54.4	38.7	6.9
upper limit	75.9	58.0	15.2
lower limit	33.8	19.4	0.0
Predicted Data			
location-free	90.6*	8.7*	0.6
4 items			
Obtained Data			
obtained data	14.1	65.6	20.3
upper limit	27.7	83.9	37.1
lower limit	0.7	47.3	3.5
Predicted Data			
location-free	73.3*	24.2*	2.5*
5 items			
Obtained Data			
obtained data	6.9	38.5	54.6
upper limit	0.0	61.2	78.0
lower limit	16.2	15.8	31.2
Predicted Data			
location-free	30.6*	56.5	12.8*

Note This analysis was based on the data from the subjects who showed positive illusory conjunctions (29 subjects in Experiment 1a, 13 subjects and 15 subjects in x-displays and no x-displays of Experiment 1b, and 13 subjects in Experiment 3).

* These data deviate from the 95% confidence interval of the obtained data.

APPENDIX D

A Pilot Experiment with Red Filled Circles and White Horizontal Lines

In a pilot experiment, I used white horizontal lines for the form feature and circles filled with the color red (i.e., red discs) for the color features. Again, the target to be searched for was a red horizontal line. The data are shown in Table 13. The average durations of each block were 11.6 frames (SD=4.7 frames), 9.2 frames (SD=4.3 frames), 10.3 frames (SD=4.8 frames), 9.7 frames (SD=5.1 frames), and 8.6 frames (SD=4.3 frames) in block 1, 2, 3, 4, and 5.

As can be seen, the feature false-alarm rate (7.3%) was not different from the conjunction false-alarm rate (6.4%), $F(1,19)-0.712$, $p=.409$, probably because of form-specific constraints (T.H. Carr, personal communication), but filler type showed a significant effect (4.2% in color filler vs. 9.4% in form fillers), $F(1,19)=22.226$, $p<.001$, and the interaction between the display type and the filler type was also significant (11.0% in the form-filler/feature condition vs. 7.8% in the form-filler/conjunction condition; 3.5% in the color-filler/feature condition vs. 5.0% in the color-filler/conjunction condition), $F(1,19)=6.941$, $p<.05$. Because the acquisition of a significant number of illusory conjunctions is prerequisite to examining the single representation view and the dual code view, we chose the empt

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empty colored circles as used in Experiments 3 and 4, instead of the red discs.

Table 13. Average Error Rates (%) in Target Displays, Feature Displays, and Conjunction Displays (Pilot Experiment with Red Filled Circles and White Horizontal Lines).

Display Type	Number of Items: three	four	five	average
(form filler)				
Miss in Target	4.3	5.8	6.0	5.4
FA in Feature	10.3	11.3	11.5	11.0
FA in Conjunction	7.3	6.5	9.8	7.8
means of FAs	8.8	8.9	10.7	
estimated IC	- 3.0	- 4.8	- 1.7	- 3.2
(color filler)				
Miss in Target	10.0	8.0	9.5	9.2
FA in Feature	3.5	4.0	3.0	3.5
FA in Conjunction	6.5	3.8	4.8	5.0
means of FAs	5.0	3.9	3.9	
estimated IC	3.0	- 0.2	1.8	1.5

Abbreviations FA = false-alarm responses in feature displays and conjunction displays; Miss = miss responses in target displays; IC = illusory conjunctions. The estimated amount of IC was computed by subtracting FA in feature displays from FA in conjunction displays.

APPENDIX E

An Example of the C-Program Used in This Research

```
/* Experiment 3
     .target: a red horizontal line
     .distractors:
     - white horizontal lines,
     - red circles or white circles filled with red dots
     .masks:
     - red and white random line mask
     - white mask
     .March 02, 1994 */

/*  headfiles  */
   #include <stdio.h>
   #include <stdlib.h>
   #include <graphics.h>
   #include <time.h>
   #include <dos.h>
   #include <string.h>

/*  define stimulus locations  */
   #define FOCUSX1 286;
   #define FOCUSX2 320;
   #define FOCUSX3 354;
   #define FOCUSY1 150;
   #define FOCUSY2 175;
   #define FOCUSY3 200;

/*  files  */
   FILE *ictask, *subjnum, *durtion;  /* datafile */

/*  subject codes */
   char durname[15];
   char filename[15];
   char subcode1; /* masks */
   char subcode2; /* the identity of the red color */
   int number;

/* stimulus set */
   char basestim[18][6]
     ={ "thhnn","tccnn","thhhn","tcccn","thhhh","tcccc",
       "hhhnn","cccnn","hhhhn","ccccn","hhhhh","ccccc",
       "chhnn","hccnn","chhhn","hcccn","chhhh","hcccc",
      };
   char reptst[72][6]; /* repeated stimulus arrays */

/* structuring data_file */
```

```
   struct
     {int target;   /* condition */
      char resp1;    /* whether there was a target or not */
      char resp2;    /* counting */
     } data[72];
   struct    /* structuring exposure time data */
     {int sum;
      int number;
      float meantm;
     } ttime;

/*  duration of stimulus  */
   int prac_dur=100;  /* duration of practice */
   int st_dur=8;  /* start duration of main experiment */
   int mdur;   /* start duration of each block */
   float meandur=0;   /* variables for duration */
   int sumdur=0;    /* of each block */
   int freqdur=0;

/*  signal for target_drawing  */
   char drawsign;
   int exist; /* index of target presence */

main()
   {
   int i;
   int g_driver = DETECT, g_mode, g_error;
   initgraph(&g_driver, &g_mode,"");
   randomize();
   screen(0);
   control_screen();
   make_datafile();
   instruc();
   screen(1);
   practice();
   main_phase();
   closegraph();
   report();
   number = number + 1;
   subjnum=fopen("b6.num","w");
   fprintf(subjnum,"%d",number);
   }

/*  screens  */
screen(int entry)
   {
   int i;
   setcolor(LIGHTBLUE);
   settextstyle(TRIPLEX_FONT,HORIZ_DIR,USER_CHAR_SIZE);
   setusercharsize(1,1,1,1);
   switch (entry) {
     case 0:
       outtextxy(150,150,"IC Final Experiment 1");
```

```
        break;
      case 1:
        outtextxy(160,150,"  Practice Phase   ");
        break;
      case 2:
        outtextxy(160,150,"  Main Experiment  ");
      };
   getch();
   setfillstyle(SOLID_FILL,BLACK);
   for(i=0;i<160;i++) {
      bar(0,0,640,i*3);
      };
   }

/* control of brightness & contrast */
control_screen()
   {
   int i;
   setgraphmode(VGAMED);
   printf("Please control the brightness and contrast of the
screen,");
   printf("\nand, press any key.");

   for(i=0;i<3;i++) {
     setfillstyle(SOLID_FILL,WHITE);
     bar(220,120+i*60,420,150+i*60);};
   getch(); cleardevice();

   gotoxy(1,1);
   printf("Please control the size of the circle vertically
and horizontally,");
   printf("\nand press any key.");
   circle(320,195,100);
   getch(); cleardevice();
   }

next_page()
   {
   gotoxy(1,24);
   printf("\n\t\t\t\t\t(Press any key to continue)");
   getch();
   cleardevice();
   }

/*  Making datafile and writing subject code  */
make_datafile()
   {
   char res1,res2;
   setgraphmode(VGAHI);

   do {
   subjnum = fopen("b6.num", "r");
   fscanf(subjnum,"%d",&number);
```

```
   gotoxy(12,6);printf("Subject number is %d, correct
?\n",number);
   gotoxy(12,7);printf("If yes, press 'y',");
   gotoxy(12,8);printf("or if you want to use a new number,
press 'n'.");
   do { res1 = getch(); } while((res1!='y')&&(res1!='n'));
   switch(res1) {
     case 'y':break;
     case 'n':
       gotoxy(12,9);
       printf("Type a new number, and 'Enter': ");
       scanf("%d",&number);
     };
   gotoxy(12,10);
   printf("mask('w' or 'p')");
   do { subcode1=getch(); }
   while((subcode1!='w')&&(subcode1!='p'));

   gotoxy(12,11);
   printf("color feature('f' or 'o')");
   do { subcode2=getch(); }
   while((subcode2!='f')&&(subcode2!='o'));

   gotoxy(12,12);
   printf("[c]ontinue or [r]estart ?: ");
   do { res2=getch(); } while((res2!='c')&&(res2!='r'));
   } while(res2 == 'r');
   sprintf(filename,"b6%c%c%d.dat",subcode1,subcode2,
number);
   sprintf(durname,"b6%c%c%d.tim",subcode1,subcode2,number);

   gotoxy(12,14);
   printf("Your data will be saved as
'b6%c%c%d.dat'",subcode1,subcode2,number);

   next_page();
   }

/* Instructions */
instruc()
   {
   char button;
   int example;

   setgraphmode(VGAMED);

   setcolor(15);
   switch(subcode1) {
     case 'p': text(11); break;
     case 'w': text(12);};
   demo_figure();
   next_page();
```

```
   setgraphmode(VGAHI);
   switch(subcode2) {
     case 'o': text(21); break;
     case 'f': text(22);};
   next_page();

   setgraphmode(VGAMED);
   for(example=0;example<4;example++) {
   delay(2000);
      switch(example) {
      case 0: examp(1); break;
      case 1: examp(2); break;
      case 2: examp(3); break;
      case 3: examp(4);};

   setgraphmode(VGAHI);
   gotoxy(1,3);
   switch(example) {
      case 0:
     printf(" In this case,");
     printf("\n there was a red horizontal line among other
stimili.");
     break;
      case 1:
     printf(" In this case, there was no red line,");
     printf("\n though some part of stimuli was red.");
     break;
      case 2:
     printf(" In this case, there was no red line,");
     printf("\n though there were some white horizontal
lines.");
     break;
      case 3:
     printf(" In this case, there was no red line,");
     printf("\n though the red color and a horizontal line
co-existed.");
     };
   printf("\n Which key do you have to press, 'z' or '/'
?");
   printf("\n Please press a correct key.");
   do { button = getch();
      } while((button!='/')&&(button!='z'));

   if(example==0) {
   printf("\n Let me show you another example.");};
   next_page();
   };
   switch(subcode2) {
     case 'o': text(31); break;
     case 'f': text(32);};
   next_page();
   }
```

```
demo_figure()
  {
  int i,j,k;

  switch(subcode1) {
    case 'p':
      for(i=0;i<30;i++) {
     for(j=0;j<23;j++) {
       k=random(2);
       if(k==1)
         {setcolor(RED);}
       else {setcolor(LIGHTGRAY);};
       rectangle(100+4*i,208+4*j,102+4*i,208+4*j);
       };
     };
      break;
    case 'w':
      setfillstyle(SOLID_FILL,WHITE);
      bar(100,208,222,300);
      };

   setcolor(LIGHTGRAY);
   circle(286,230,12); circle(320,230,12);
circle(354,230,12);
   circle(286,255,12); circle(320,255,12);
circle(354,255,12);
   circle(286,280,12); circle(320,280,12);
circle(354,280,12);
   line(286-12,230,286+12,230);
   line(286-12,255,286+12,255);
   line(320-12,280,320+12,280);
   setcolor(RED);
   line(354-12,255,354+12,255);

  switch(subcode1) {
    case 'p':
      for(i=0;i<30;i++) {
     for(j=0;j<23;j++) {
       k=random(2);
       if(k==1)
         {setcolor(RED);}
       else {setcolor(LIGHTGRAY);};
       rectangle(430+4*i,208+4*j,432+4*i,208+4*j);
       };
     };
      break;
    case 'w':
      setfillstyle(SOLID_FILL,WHITE);
      bar(430,208,550,300);
      };
  }

/* Texts */
```

```
text(int vol)
   {
   int i; char ch;
   FILE *txt;
   i=0;

   delay(2000);
   switch(vol) {
      case 11:
     txt = fopen("b611.txt","r");
     break;
      case 12:
     txt = fopen("b612.txt","r");
     break;
      case 21:
     txt = fopen("b621.txt","r");
     break;
      case 22:
     txt = fopen("b622.txt","r");
     break;
      case 31:
     txt = fopen("b631.txt","r");
     break;
      case 32:
     txt = fopen("b632.txt","r");
     break;
      case 4:
     txt = fopen("b64.txt","r");
      };
   gotoxy(9,4);
   while((ch=getc(txt))!=EOF) {
      printf("%c",ch);
      delay(20);
      i++;
      if((i>52)&&(ch==32)) {
      printf("\n\t"); i=0;};
      };
      fclose(txt);
   }

/* Presenting Example */
examp(int ex)
   {
   int i;
   char x;
   cleardevice();

   setgraphmode(VGAMED);
   delay(1000);

   setactivepage(1);
   mask();
   sound(2000); delay(500); nosound();
```

```
   setvisualpage(1);
   setactivepage(0);
   cleardevice();
   switch(ex) {
      case 1:
      draw_circle();
      draw_target(2,'t');
      draw_target(7,'h');
      draw_target(5,'h');
      draw_target(0,'h');
      break;
      case 2:
      draw_circle();
      draw_target(3,'c');
      draw_target(8,'c');
      draw_target(5,'c');
      draw_target(0,'c');
      break;
      case 3:
      draw_circle();
      draw_target(2,'h');
      draw_target(7,'h');
      draw_target(5,'h');
      break;
      case 4:
      draw_circle();
      draw_target(3,'c');
      draw_target(8,'h');
      draw_target(5,'h');
      draw_target(0,'h');
      };
   delay(1000);
   setvisualpage(0);
   delay(2000);
   setvisualpage(1);
   delay(500);
   }

/* Reading Stimulus Arrays and Randomizing Inter-Trials */
read_stimuli()
   {
   int i,ii,j,k;
   char temp[6];      /* randomizing stimulus arrays */
   int radnum; /* randomizing stimulus arrays */
   ii=0;

   for(k=0;k<4;k++) {
     for(i=0;i<18;i++) {
       for(j=0;j<5;j++) {
      reptst[ii][j] = basestim[i][j];}; /* end of for(j) */
       reptst[ii][5] = '\0';
       ii++;
       }; /* end of for(i) */
```

```
      };
   for(i=0;i<72;i++) {     /* randomizing stimulus arrays */
      radnum = random(72);
      for(j=0;j<6;j++) {
         temp[j] = reptst[i][j];};
      for(j=0;j<6;j++) {
         reptst[i][j] = reptst[radnum][j];};
      for(j=0;j<6;j++) {
         reptst[radnum][j] = temp[j];};
      }; /* end of for(i) */
   }

/* Main Experiment */
main_phase()
   {
   int s1,s2,mi,mmi,i,dd;
   char t1;

   cleardevice();
   setgraphmode(VGAHI);
   text(4); getch();
   cleardevice();
   screen(2);

   mdur=st_dur;
   for(mi=0;mi<6;mi++) {
   setgraphmode(VGAMED);
   delay(2000);

   read_stimuli();
   experiment();
   if(mi > 0) {
      write_data();
      write_durtion_data();
      };
   cleardevice();
   delay(1000);

   mmi=mi+1;
   if(mi<5) {
     setgraphmode(VGAHI);
     gotoxy(13,12);
     printf("You finished %d block.",mmi);
     gotoxy(13,13);
     printf("How was this experiment ?");
     gotoxy(13,14);
     printf("Take a rest, and if ready, press 'ENTER'.");
     } /* end of if(mi) */
   else if(mi==5) {
     setgraphmode(VGAHI);
     gotoxy(16,10);
     printf("You have done all.\n");
     gotoxy(16,11);
```

```
     printf("Thank you very much.");
     for(s1=1;s1<5;s1++) {
     s2=1;
     for(s2=1;s2<5;s2++) { sound(100 * s2); delay(150);
nosound();};};
     gotoxy(16,13);
     printf("If you want to know your data, press
'ENTER'.");
     }; /* end of else if(mi) */
     do {t1 = getch();} while(t1!=13);
     cleardevice();
   } /* end of for(mi) */
   }

/* Presenting Stimuli */
practice()
   {
   int pos[9],postemp,posrad;  /* randomizing locations */
   int i,j,jj,k,l,m;       /* first, second index of
stimulus array */
   char resp1,resp2;  /* response indices */
   unsigned int pnt1,pnt2;  /* synchronizing indices */

   read_stimuli();

   for(i=0;i<20;i++) {
      setgraphmode(VGAMED);

      /* randomizing circle locations */
      for(j=0;j<9;j++) { pos[j]=j;};
      for(j=0;j<9;j++) {
      posrad=random(9);
      postemp=pos[j];
      pos[j]=pos[posrad];
      pos[posrad]=postemp;
      };
      setactivepage(1);
      mask();
      sound(2000); delay(500); nosound();

      setvisualpage(1);
      setactivepage(0);
      cleardevice();

      /* target drawing */
      draw_circle();
      for(k=0;k<5;k++) {
      drawsign = reptst[i][k];
      draw_target(pos[k],drawsign);
      };
      delay(1000);
      do {
      pnt1=inportb(0x3DA);
```

```
      pnt2=pntl ^ 0x08;
      } while(pnt2 & 0x08);
      setvisualpage(0);

      bdos(0x0c,0,0);
      delay(5);
      for(l=0;l<prac_dur;l++) {
      do {
         pntl=inportb(0x3DA);
         pnt2=pntl ^ 0x08;
         } while(pnt2 & 0x08);
         delay(5);
      };
      setvisualpage(1);
      delay(500);

      /* response checking */
      printf("a red line('/' key), or not('z' key) ?");
      do {
      respl = getch();
      if((respl!='z')&&(respl!='/'))
        {gotoxy(20,18);
         printf("\nFalse key !!   Please respond once
more.\n");
         sound(500); delay(500); nosound();};
        } while((respl!='/')&&(respl!='z'));
     cleardevice();
     printf("\nHow many items? 3 to 5");
      do {
      resp2 = getch();
      if((resp2!='3')&&(resp2!='4')&&(resp2!='5'))
        {gotoxy(20,18);
        printf("\nFalse key !!   Please respond once
more.\n");
         sound(500); delay(500); nosound();};
        } while((resp2!='3')&&(resp2!='4')&&(resp2!='5'));
     cleardevice();
     delay(1000);
     };
   }


/* Presenting Stimuli */
experiment()
   {
   int pos[9],postemp,posrad;  /* randomizing locations */
   int i,j,k,l,m;       /* first, second index of stimulus
array */
   char respl,resp2; int tresp2;  /* response indices */
   unsigned int pntl,pnt2;  /* synchronizing indices */
   int dur;
   int ti=0,error=0;
   int blcsum=0,blcnum=0;
```

```
   int truth,z;

   dur=mdur;

   for(i=0;i<72;i++) {
      setgraphmode(VGAMED);

      /* randomizing locations */
      for(j=0;j<9;j++) {pos[j]=j;};
      for(j=0;j<9;j++) {
      posrad=random(9);
      postemp=pos[j];
      pos[j]=pos[posrad];
      pos[posrad]=postemp;
      };
      exist=0;
/************** stimulus presentation *************/
      setactivepage(1);
      mask();
      sound(2000); delay(500); nosound();
      setvisualpage(1);
      setactivepage(0);
      cleardevice();

      /* target drawing */
      draw_circle();

      for(k=0;k<5;k++) {
      drawsign = reptst[i][k];
      draw_target(pos[k],drawsign);
      };
      delay(1000);

      do {
      pnt1=inportb(0x3DA);
      pnt2=pnt1 ^ 0x08;
      } while(pnt2 & 0x08);
      setvisualpage(0);
      bdos(0x0c,0,0);
      delay(5);
      for(l=0;l<dur;l++) {
     do {
       pnt1=inportb(0x3DA);
       pnt2=pnt1 ^ 0x08;
       } while(pnt2 & 0x08);
     delay(5);
     };

      setvisualpage(1);
      delay(500);
/************************************************/
      /* response checking */
      gotoxy(23,17);
```

```
       printf("a red line('/' key), or not('z' key) ?");

       do {
       resp1 = getch();
       if((resp1!='z')&&(resp1!='/'))
         {gotoxy(20,18);
          printf("\nFalse key !!   Please respond once
more.\n");
          sound(500); delay(500); nosound();};
         } while((resp1!='/')&&(resp1!='z'));

       if(((resp1 == '/')&&(exist == 1))||((resp1 ==
'z')&&(exist == 0)))
      { data[i].resp1='C';}
       else
      {
      data[i].resp1='I';
      error++;
      }; /* end of else(exist) */

      cleardevice();
      gotoxy(25,17);
      printf("\nHow many items? - 3 to 5");
      do {
       resp2 = getch();
       if((resp2!='3')&&(resp2!='4')&&(resp2!='5'))
         {gotoxy(20,18);
         printf("\nFalse key !!   Please respond once
more.\n");
          sound(500); delay(500); nosound();};
         } while((resp2!='3')&&(resp2!='4')&&(resp2!='5'));
      cleardevice();
      tresp2 =atoi(&resp2);
      data[i].resp2=tresp2;
      for(z=0;z<36;z++) {
      truth=strcmp(&reptst[i][0],&basestim[z][0]);
      switch(truth){
        case 0: data[i].target = z;break;
        default: break;
        };
      };

        ti++;
      blcsum=blcsum+dur;
      blcnum++;
      if(ti == 10) {
      switch(error) {
         case 0:
           dur=dur-2; break;
         case 1:
           dur=dur-1; break;
         case 2:
           dur=dur; break;
```

```
        case 3:
          dur=dur; break;
        case 4:
          dur=dur+1; break;
        default:
          dur=dur+2;
        }; /* end of switch(error) */
      if(dur<2) { dur=2;};
      ti = 0;
      }; /* end of if(ti) */

      delay(1000);
      };  /* end of for(i) */
      mdur = dur;

      ttime.sum=blcsum;
      ttime.number=blcnum;
      ttime.meantm=blcsum/blcnum;
    }

mask()
    {
    switch(subcode1)
      {
      case 'w': white_mask(); break;
      case 'p': pattern_mask();
      };
    }

/* Drawing Mask Display */
white_mask()
    {
    setfillstyle(SOLID_FILL,WHITE);
    bar(260,128,380,220);
    }

pattern_mask()
    {
    int i,j,k;
    for(i=0;i<30;i++) {
      for(j=0;j<23;j++) {
        k=random(2);
        if(k==1)
       {setcolor(RED);}
        else {setcolor(LIGHTGRAY);};
        rectangle(260+4*i,128+4*j,262+4*i,128+4*j);
        };
      };
    }

draw_target(int pos, char drawsign)
    {
    int focusx,focusy;
```

```
    switch(pos) {
       case 0: focusx = FOCUSX1; focusy = FOCUSY1; break;
       case 1: focusx = FOCUSX2; focusy = FOCUSY1; break;
       case 2: focusx = FOCUSX3; focusy = FOCUSY1; break;
       case 3: focusx = FOCUSX1; focusy = FOCUSY2; break;
       case 4: focusx = FOCUSX2; focusy = FOCUSY2; break;
       case 5: focusx = FOCUSX3; focusy = FOCUSY2; break;
       case 6: focusx = FOCUSX1; focusy = FOCUSY3; break;
       case 7: focusx = FOCUSX2; focusy = FOCUSY3; break;
       case 8: focusx = FOCUSX3; focusy = FOCUSY3;
       };
    switch(drawsign) {      /* drawing stimuli */
       case 't':
      setcolor(RED);
      line(focusx-12,focusy,focusx+12,focusy);
      exist=1;
      break;
       case 'h':
      setcolor(LIGHTGRAY);
      line(focusx-12,focusy,focusx+12,focusy);
      break;
       case 'n':
      break;
       case 'c':
      switch(subcode2) {
        case 'o':
          setcolor(RED);
          circle(focusx,focusy,12);
          break;
        case 'f':
          setcolor(LIGHTGRAY);
          circle(focusx,focusy,12);
          setfillstyle(SOLID_FILL,RED);
          fillellipse(focusx, focusy, 12, 9);
          };
      };
      }

draw_circle()
    {
    setcolor(LIGHTGRAY);
    circle(286,150,12); circle(320,150,12);
circle(354,150,12);
    circle(286,175,12); circle(320,175,12);
circle(354,175,12);
    circle(286,200,12); circle(320,200,12);
circle(354,200,12);
    }

/* Writing Data to Datafile */
write_data()
    {
    int di = 0;
```

```
   if((ictask = fopen(filename, "a")) == NULL) {
      printf("Can't open file '%s'", filename);
      exit(0); };
   for(di=0;di<72;di++) {
      fprintf(ictask, "%d%c%d\n",
        data[di].target,data[di].resp1,data[di].resp2);
      };
   fclose(ictask);
   }
/* Writing duration data to duration-data file */
write_durtion_data()
   {
   if((durtion = fopen(durname, "a")) == NULL) {
      printf("Can't open file '%s'", durname);
      exit(0); };
   fprintf(durtion, "%d %d %4.2f\n"
     ,ttime.sum, ttime.number, ttime.meantm);
   fclose(durtion);
   }

/* Reporting Data Summary */
report()
   {
   int i,j;
   int c_freq3,c_freq4,c_freq5;
   int i_freq3,i_freq4,i_freq5,display;
   char cha,res;
   FILE *icdata,*durdata;

   struct   /* structuring data */
   {
   int cond;   /* display condition */
   char acrt;    /* whether there was a target or not */
   int acnt;  /* how many item there was presented */
   } rptdata[360];
   struct   /* structuring data */
   {
   int sum;   /* display condition */
   int freq;    /* whether there was a target or not */
   float mean;  /* how many item there was presented */
   } exposure[5];

   if((icdata = fopen(filename,"r"))==NULL)
     { printf("fopen failed.\n");
       exit(0);
     }; /*  end of if  */
   if((durdata = fopen(durname,"r"))==NULL)
     { printf("fopen failed.\n");
       exit(0);
     };  /*  end of if  */

   for(i=0;i<360;i++) {
     fscanf(icdata,"%d",&rptdata[i].cond);
```

```
      rptdata[i].acrt=getc(icdata);
      fscanf(icdata,"%d\n",&rptdata[i].acnt);
      };  /* end of for(i) */
    for(i=0;i<5;i++) {
      fscanf(durdata,"%d",&exposure[i].sum);
      fscanf(durdata,"%d",&exposure[i].freq);
      fscanf(durdata,"%f",&exposure[i].mean);
      };   /*  end of for(i) */

    printf("Filename : %s\n",&filename);

    for(i=0;i<18;i++) {
      c_freq3=0; c_freq4=0; c_freq5=0;
      i_freq3=0; i_freq4=0; i_freq5=0;
      for(j=0;j<360;j++) {
      if(i==rptdata[j].cond) {
         switch(rptdata[j].acrt) {
           case 'C':
           switch(rptdata[j].acnt) {
              case 3:c_freq3++;break;
              case 4:c_freq4++;break;
              case 5:c_freq5++;
              };
           break;
           case 'I':
           switch(rptdata[j].acnt) {
              case 3:i_freq3++;break;
              case 4:i_freq4++;break;
              case 5:i_freq5++;
              };
           }; /* end of switch(rptdata) */
         }; /* end of if(i) */
      }; /* end of if(j) */
      if(i==0) {
      printf("\nB1(%3.2f)", exposure[0].mean);
      printf("  - B2(%3.2f)", exposure[1].mean);
      printf("  - B3(%3.2f)", exposure[2].mean);
      printf("  - B4(%3.2f)", exposure[3].mean);
      printf("  - B5(%3.2f)", exposure[4].mean);
      printf("\n\n\t    (count3)       (count4)
(count5)");
      };
      display=i;

      switch(display) {
      case 0: printf("\nTHH        ");break;
      case 1: printf("\nTCC        ");break;
      case 2: printf("\nTHHHH      ");break;
      case 3: printf("\nTCCC       ");break;
      case 4: printf("\nTHHHH      ");break;
      case 5: printf("\nTCCCC      ");break;
      case 6: printf("\n\nHHH        ");break;
      case 7: printf("\nCCC        ");break;
```

```
case 8: printf("\nHHHH     ");break;
case 9: printf("\nCCCC     ");break;
case 10: printf("\nHHHHH    ");break;
case 11: printf("\nCCCCC    ");break;
case 12: printf("\n\nCHH      ");break;
case 13: printf("\nHCC      ");break;
case 14: printf("\nCHHH     ");break;
case 15: printf("\nHCCC     ");break;
case 16: printf("\nCHHHH    ");break;
case 17: printf("\nHCCCC    ");break;
};
printf("%5d(%5d)   %5d(%5d)    %5d(%5d)",
    c_freq3,i_freq3,c_freq4,i_freq4,c_freq5,i_freq5);
};
do { res = getch(); } while(res!='q');
}
```

/* b611.txt */

Thank you very much for coming !! This experiment is on investigation of 'Visual Search Skills'. Each trial consists of three sequential displays: a red/white square patch, a target display, and a red/white square patch. At first, you will see a red/white random dot square(see below) at the center of the computer screen and will hear a warning beep. This display will be replaced by a target display. The target display consists of 9 small circles and/or some horizontal lines. Lastly you will see the red/white random-dot square again. This sequence is shown below:

/* b612.txt */

Thank you very much for coming !! This experiment is on investigation of 'Visual Search Skills'. Each trial consists of three sequential displays: a white square patch, a target display, and a white square patch. At first, you will see a white square(see below) at the center of the computer screen and will hear a warning beep. This display will be replaced by a target display. The target display consists of 9 small circles and/or some horizontal lines. Lastly you will see the white square again. This sequence is shown below:

/* b621.txt */

In this experiment, your task is to check whether the target display contains any red horizontal line. Sometimes, the target set might contain a red horizontal line, but sometimes it does not contain any red horizontal line, though some circles are red and/or some circles contain white horizontal lines. If your answer is 'yes', please press '/', or if 'no', press 'z'. If you press any other keys that are not appropriate responses, a warning message will appear, asking you to respond again. Now I will show you 4 samples of trials. Please try to find any red horizontal line. For example, you might see the following sequence of stimuli.

/* b622.txt */

In this experiment, your task is to check whether the target display contains any red horizontal line. Sometimes, the target set might contain a red horizontal line, but sometimes it does not contain any red horizontal line, though some circles are filled with red dots and/or some circles contain white horizontal lines. If your answer is 'yes', please press '/', or if 'no', press 'z'. If you press any other keys that are not appropriate responses, a warning message will appear, asking you to respond again. Now I will show you 4 samples of trials. Please try to find any red horizontal line. For example, you might see the following sequence of stimuli.

/* b631.txt */

Is it easy? As you have seen, only the first example contained a red horizontal line. In the main experiment, you will also be asked to count the horizontal lines (whether these are white or red) and circles filled with red dots, and to report their sum. For example, if the target display contained one circle filled with red dots and three horizontal lines, the correct number is 'four' from one plus three. If the target display contains circles filled with red dots and one red horizontal line, the correct answer is three from two plus one. If there are one red horizontal line and four white horizontal lines without any circle filled with red dots, then the correct answer is five from one plus four. The possible number of items are '3', '4', and '5'. So after you press '/' or 'z', please press '3', '4', or '5' properly. So, on every trial, you have to respond twice: checking a red horizontal line, and counting horizontal lines and circles filled with red circles. From now on you will get 20 practice trials. If you are ready, please press any key. Thank you very much.

/* b632.txt */

Is it easy? As you have seen, only the first example contained a red horizontal line. In the main experiment, you will also be asked to count the horizontal lines (whether these are white or red) and circles filled with red dots, and to report their sum. For example, if the target display contained one circle filled with red dots and three horizontal lines, the correct number is 'four' from one plus three. If the target display contains circles filled with red dots and one red horizontal line, the correct answer is three from two plus one. If there are one red horizontal line and four white horizontal lines without any circle filled with red dots, then the correct answer is five from one plus four. The possible number of items are '3', '4', and '5'. So after you press '/' or 'z', please press '3', '4', or '5' properly. So, on every trial, you have to respond twice: checking a red horizontal line, and counting horizontal lines and circles filled with red circles. From now on you will get 20 practice trials. If you are ready, please press any key. Thank you very much.

/* b64.txt */

Now, it seems that you have enough practice. You can start the main experiment. The main experiment consists of 6 blocks, each of which contains 72 trials, and a brief time-break will be given at the end of each block. If you are ready, press any key. Thank you very much.

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