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THE EFFECTS OF FORM AND LOCATION CUING ON TARGET IDENTIFICATION

BY

Andrew D. Macquistan ©

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THE UNDERSIGN CERTIFY THAT THEY HAVE READ, AND RECOMMEND TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH, A THESIS ENTITLED THE EFFECTS OF FORM AND LOCATION CUING ON TARGET IDENTIFICATION SUBMITTED BY ANDREW D. MACQUISTAN IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS.

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ABSTRACT

In a recognition task, subjects were cued with the possible form and possible location of a briefly presented target item. Reaction time to identify the target item was reduced by both the correct cuing of form and the correct cuing of location. These effects occurred for items that differed by a visual feature (line orientation), and for items that differed only in an arrangement of features. The results have implications for dual stage theories of visual processing, such as feature integration theory (Treisman, 1988) and similarity theory (Duncan and Humphreys, 1989). They indicate that a target's location and a target's form are coded at the initial processing stages, and that the initial stages of visual processing encode some information about the inter-relationships of object parts. The data do not support two stage models that suggest only simple feature information is registered initially (feature integration theory), but do support two stage models in which at least some configural properties of stimuli are registered early (similarity theory). The implications of these findings for theories of spatial indexing and the issue of early semantic access are also discussed.

Acknowledgement

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INTRODUCTION

Human observers are extremely flexible in responding to change in the visual environment, but are also extremely limited in the amount of sensory data that they can respond to at any one time (Broadbent, 1982; Hoffman, 1978; 1979). As a result, current theories of visual information processing propose that the analysis of a visual scene is divided into two stages (e.g. Treisman, 1988; Duncan and Humphreys, 1989; Neisser, 1967; Pylyshyn, 1984; 1989). The first, or "preattentive," stage consists of a set of basic processes that register, and possibly organize, perceptual information (Duncan and Humphreys, 1989; Neisser, 1967). Usually, these processes are described as having large or unlimited capacity, and as operating in parallel (Broadbent, 1982; Duncan, 1980; 1989; Duncan and Humphreys, 1989; Hoffman, 1978; 1979; Neisser, 1967; Treisman, 1988; 1986; Treisman and Gelade, 1980; Treisman and Gormican, 1988). The second, or "attentive," stage is limited in processing capacity, and its output allows for responses to be initiated to stimuli. In a two stage theory, the flexibility of human observers is attributed to preattentive processes and capacity limitations are attributed to attentive processing (Neisser, 1967; Hoffman, 1978; 1979).

Different types of two stage theories make competing claims about the extent of visual analysis at the preattentive stage (Stage 1). Late selection models, such as similarity theory (Duncan, 1980, 1981; Duncan and Humphreys, 1989), propose that in Stage 1 all stimuli are analyzed up to the assignment of semantic category and meaning. In contrast, early selection theories, such as feature integration theory (Treisman, 1985; 1988; Treisman and Gelade, 1980), propose that perceptual information is registered in parallel by Stage 1 processes, but this information is not semantically analysed until attentive, or Stage 2, processing commences (Duncan, 1981; 1985; 1989; Duncan and Humphreys, 1989; Khaneman and Treisman, 1984; Treisman, 1986; 1988). Indeed, in feature integration theory, holistic properties of objects, such as the arrangement of lines in letters (Treisman and Gelade, 1980, Experiment 4), or the assignment of colors to shapes (Treisman, 1988; Treisman and Gelade, 1980; Treisman and Schmidt, 1982), are not reliably represented, and not accessible for conscious awareness, until after the application of serial attention (Khaneman and Treisman, 1983; Treisman, Khaneman and Burkell, 1983; Treisman and Schmidt, 1982).

This paper reports the results of two experiments that tested competing predictions of two representative late and early selection theories: similarity theory (Duncan and Humphreys, 1989), and feature integration theory (Treisman and Gelade, 1980). The paper is organized as follows: First, the basic characteristics of the two models are briefly reviewed to show that they make different predictions about the preattentive availability of information concerning object locations and form. Second, the results of two experiments in which the location and form of a target were precued are presented. The results of both experiments support the assumptions of similarity theory, and are not consistent with feature integration theory. Finally, these interpretations and data are discussed in light of other research on attentional cuing and visual processing.

LATE AND EARLY SELECTION MODELS

Similarity Theory

One example of a late selection two stage model is similarity theory (Duncan and Humphreys, 1989). In similarity theory, Stage 1 is called the stage of perceptual description, and its outputs are selectively transfered to Stage 2, which is called visual short term memory (VSTM). During Stage 1, complex representations of objects are formed, called structural units (c.f. Palmer, 1977). Structural units encode all possible information about a perceptual object, such as its location in space and its form. This information includes the holistic properties that Treisman proposes arise after attention (Khaneman, Treisman and Burkell, 1983; Treisman, Khaneman and Burkell, 1983; Treisman and Schmidt, 1982). Any single structural unit may be part of a higher structural unit, and contain multiple structural units (Duncan and Humphreys, 1989) as an organized hierarchy of object parts (see also Marr and Nishihara, 1977). While the stage of perceptual description is outside of conscious awareness, the processes at this stage do have access to aspects of meaning in memory, and classification according to semantic categories is seen to have occurred before selection to VSTM. Stage 1 representations are selected to VSTM according to how closely their contents resemble the information required by higher cognitive processes (also refered to as the target template).

In similarity theory (Duncan and Humphreys, 1989), the contents of VSTM are equivalent to the contents of awareness, and responses can only be initiated on the basis of what is "in" VSTM. The process of selection therefore determines an observer's response times and the accuracy of responding. Selection depends on a process of weighting structural units in terms of their similarity to the target template, and is strongly affected by segmentation and grouping processes that occur at the stage of perceptual description. Segmentation and grouping serves to link items together in terms of their shared perceptual qualities. This linking is based on any of the information contained in the structural unit (Duncan and Humphreys, 1989); thus grouping can occur by proximity (similar locations), shape, common motion, or any other attribute, including semantic qualities. The assignment of weight values exploits this grouping, with similar items being assigned similar weights. Units similar to the template are weighted more highly than units dissimilar to the template. The most highly weighted item gains access to VSTM, allowing arbitrary responses to be made to it. When a structural unit is selected to VSTM, those units that it is grouped with tend be selected to VSTM as well.

In similarity theory, selection to VSTM can proceed on the basis of any information that can be represented in the structural units. Physical properties of the stimulus, such as location, motion or color, can determine selection, as can semantic qualities, such as categorical meaning. This assumption, unqualified, makes a strong prediction: If subjects are required to select stimuli by color, location or common category, they should be able to do so with relative ease, regardless of the selection criteria used. To qualify this assumption of their theory, Duncan and Humphreys (1989) propose that the processes of grouping and selection use the information encoded in the structural units with different relative efficiencies. Thus, while grouping processes may use color information very efficiently relative to location information, processes of selection might use color information less efficiently, relative to location information. Certain kinds of information, such as information about location, permit better selection than other kinds of information (Duncan, 1981; Duncan and Humphreys, 1989). This qualification permits similarity theory to account for empirical results that show an advantage for selection by location in cuing studies (Eriksen and Hoffman, 1973; Posner, Snyder and Davidson, 1980; Briand and Klein, 1987).

For example, Eriksen and Hoffman (1973) cued subjects with a bar marker at one of four possible peripheral locations where a target letter could occur, either simultaneously with the target's onset, or 50, 100 or 150 msec before the target onset. Significant facilitation in response time was found with increasing inter-stimulus interval (ISI). Neutral and control conditions ruled out the possibility of masking or of simple temporal warning as the source of the effect. To explain such findings, Duncan (1981) has suggested that knowledge about the expected position of a target item does not affect the quality of the target's perceptual representation, but merely affects how easily that target is selected to VSTM. If subjects lack advanced knowledge of position, then they might select a non-target location for examination by Stage 2. Thus, in experiments such as Eriksen and

Hoffman (1973), blank spaces serve as distractor items, which in turn suggests that there is no essential difference between visual search and attentional cuing paradigms (Duncan, 1981; 1985; Prinzmetal, Presti and Posner, 1986). Any type of information represented at the initial stage of processing can serve to guide selection; however, selection by location tends to be the most efficient (Duncan, 1981).

In summary, similarity theory asserts that location and form information are coded together in the structural units constructed during Stage 1. This implies that both location and form should affect selection when used as cues in an experiment like that of Eriksen and Hoffman (1973). An advantage for the cuing of location information over the cuing of form information could simply depend on the greater discriminablity of location relative to that of form. Advanced specification of form, provided that the information was discriminable enough, should therefore facilitate the selection of a target item to VSTM as does the advanced specification of location. One would therefore predict that highly discriminable form cues should result in some form cuing effect (as demonstrated by Duncan and Humphreys, 1989). These predictions of similiarity theory differ considerably from those of feature integration theory, which is considered next.

Feature Integration Theory

An important example of an early selection two stage model is feature integration theory. Feature integration theory differs from similarity theory in proposing that properties such as the arrangement of line segments can only be recognised after attentive processing (Treisman and Gelade, 1980). Further, the theory proposes that information about the location of stimuli is made availble at a different processing stage than stimuli's form.

In feature integration theory's first stage of processing (Treisman and Gelade, 1980), the visual scene is analysed in terms of independent features and dimensions. The theory has tended to leave the specification of exactly what are features and what are dimensions as an empirical issue, defined by a set of diagnostic tests (Treisman, 1988). However, Treisman and Schmidt (1982; see also Treisman and Gormican, 1988) have proposed that a dimension is the set of possible, mutually exclusive perceptual properties that an object can have -- for example, the set of colors, orientations or curvatures (Treisman, 1985). A feature is seen to be a particular value on a dimension -- for example, "blue," "tilted" or "curved". Note whatever value a stimulus has on a particular dimension has no implications for the value it has on another dimension. That something is blue does not imply anything about its degree of curvature. Independent feature analyzers process the entire visual field, producing either activation values on feature maps (Treisman, 1988), or values in independent modules for each perceptual dimension of the stimulus (Treisman, 1988; Treisman and Gormican, 1988), and code the presence of unique features in the visual world. The coding proceeds in parallel over visual space, and in parallel over the different dimensions of the stimulus (Treisman, 1988; Treisman and Gelade, 1980; Treisman and Gormican, 1988). While locations are coded at the level of feature registration (the maps are retinotopic in organization), it is a central proposition of feature integration theory that only the presence of activation in a module or a feature map, not the location of the activation, is directly available to central processes (Treisman, 1988).

In order to retrieve the information of <u>where</u> a particular feature is located, or to determine what other feature values are present at a location, focal attention (i.e., Stage 2 processes) must be directed to the location. Focal attention is seen to operate over a "master map" of locations, each location on the master map being linked to all the corresponding locations on the feature maps (Treisman, 1988). When attention is directed to a location, the feature values occurring at that location can be retrieved, and their arrangement encoded in a representation called an object file. When attention is not directed to the location of co-occurring features, then the non-attended features should randomly recombine, leading to an incorrect percept called an illusory conjunction (Treisman, 1988; Treisman and Schmidt, 1982; see, however, Houck and Hoffman, 1986, and Tsal, 1989).

In feature integration theory, location information is only recoverable from an object file (Khaneman and Treisman, 1984; Treisman, 1988). Object files are constructed during Stage 2, and serve as temporary, holistic representations of perceptual objects. The contents of an object file are responsible for conscious awareness (Treisman, 1988). Attention serves to mediate the inflow of information to an object file, the semantic identification of the contents of the object file, and, possibly, the retrieval of information from the object file (Khaneman and Treisman, 1984). While the feature information contained in an object file can only be changed by Stage 2 processes, the location information contained in the object file is updated without attention's mediation (Treisman, 1988). Thus an object file keeps track of the identity of an object over its movements in space. An object file exists only for the perceptual life of the object it represents (Treisman, 1986). A new object file is created for each new object in the visual field, and information does not carry over from one file to the next (Khaneman, Treisman and Burkell, 1983). Thus, in feature integration theory, object files serve the purpose of individuating perceptual entities. In terms of processing cost, maintaining an object file (ie, not updating its contents) is less costly than updating its contents, which is less costly than the creation of a new object file (Khaneman, Treisman and Burkell, 1983).

Much of the support for feature integration theory has derived from its predictions of reaction time patterns in visual search tasks (Treisman, 1985; 1986; 1988; Treisman and Gelade, 1980). In such tasks, detection times for targets possessing a feature unique in the visual field are independent of the number of distractors present in the field (this is referred to as the "pop out effect"). Detection times for targets defined only by a unique combination of features (conjunction targets) increase with increasing numbers of distractors. The basic feature integration model attributes the pop out effect to Stage 1 processes that allow the detection of form independent of location. For conjunction stimuli, the relationship between detection time and the number of targets is attributed to the preliminary retrieval of location information required by Stage 2 processes (Treisman, 1985; 1986; 1988; Treisman and Gelade, 1980; Treisman and Souther, 1982). Attention must interrogate locations serially in order to correctly conjoin the feature information at each location. Only after processing by attention can a conjunction target be identified.

In contrast to similarity theory, feature integration theory suggests that there are two different kinds of form information. For any item that can be identified by a unique feature, such as a unique orientation or color, form information can be retrieved independently of location information. The preattentive access to feature map activity proposed in feature integration theory predicts this result. For items that differ only in an arrangement of features, the retrieval of correct form information must be preceded by selecting the correct location to retrieve it from (Briand and Klein, 1987; Prinzmetal et al, 1986; Treisman, 1985; 1988; Treisman and Gelade, 1980; Treisman and Gormican, 1988; see also Nakayama and Mackaben, 1989, Experiment 1).

<u>The Group Scanning Account</u>. Treisman and Gormican (1988) have recently suggested a modified version of feature integration theory, called the group scanning model. In this model, the master map of locations still serves as an index of locations, as in earlier versions of feature integration theory (Treisman 1988; Treisman and Gormican, 1988), but it also serves as an initial stage of feature registration. All the feature information in a scene is registered on this one map and analysis by separate dimensions then follows. It is further suggested that subjects

can only respond to those items which are included in the focus of attention; however, the size of the focus of attention can be increased or decreased depending on the discriminability of the stimuli (for features) or the need to conjoin features (Treisman, 1988; Treisman and Gormican, 1988). When features are poorly discriminable, or there is a need to accurately conjoin them, subjects must narrow their attention's focus. When features are highly discriminable, and there is no need to accurately conjoin them, the focus of attention can be expanded to contain the entire array. Subjects can then detect the presence of unique features by the level of activation on the appropriate feature map (Treisman and Gormican, 1988). Thus, in group scanning, features are still identified in parallel across locations, but their detection is mediated by a diffuse "spotlight of attention" (Treisman and Gelade, 1980; Treisman and Gormican, 1988). To account for previous results showing an independence of localization and identification for feature as opposed to conjunction stimuli, Treisman and Gormican (1988) propose that localization within the spotlight of attention is relatively coarse when the spotlight covers a wide area. For conjunction stimuli, localization is still preliminary to identification, since the narrowed focus of attention must be directed to the correct location for feature integration to proceed.

The motivation for the group scanning model is to account for results that suggest some coding of conjunction stimuli is possible without attention (Houck and Hoffman, 1986; Treisman, 1988). In particular, it is possible to produce color-orientation after-effects (the McCollough illusion) when attention has been diverted from the locations of the inducing stimuli. Placing the master map early, and suggesting that information is registered at this stage, provides an account of the McCollough illusion results. The group scanning account does blur the sharp distinction initially made between feature and conjunction stimuli (Treisman and Gelade, 1980; see Treisman and Gormican, 1988;

Duncan and Humphreys, 1989, for commentary). In group scanning, all recognition is post-attentional. In general, however, the group scanning account makes the same assertions about access to location and form information as feature integration theory. For feature stimuli, form is much more easily retrievable than location. For conjunction stimuli, retrieval of location must precede the correct identification of form.

EXPERIMENT I

The representative late selection (e.g. Duncan and Humphreys, 1989) and early selection (eg Treisman, 1988) models discussed above make different assertions about the role of stimulus form and of stimulus location in visual processing. One way to illustrate these differences is to consider Duncan's (1981) discussion of late selection theories and attention cuing paradigms. Imagine an experiment where the subject's task is to identify which one of two items was briefly presented on a trial. The form and location of the target randomly varies from trial to trial. Prior to the onset of the target, subjects are given a valid or invalid location cue that could be the same or different in form as the target item. In one condition the alternative targets differ in terms of a simple feature, while in another they differ only by their arrangement of features. Similarity theory (Duncan and Humphreys, 1989; see also Duncan, 1981) predicts that if subjects were given a highly discriminable, valid cue for the form of the to-be expected item, then they should show improvements in reaction time and accuracy to identify or detect the post cue item. Of course, improvements in reaction time should also occur to a correct location cue. An interaction of these effects would be expected, since, in similarity theory, they arise at the same locus in the processing of stimuli (in similarity theory, location and form information differ in neither representation nor role). Similarity theory asserts that all information about the object is encoded at Stage 1, so whether the alternative targets differ in a feature or by an arrangement of features should not affect the pattern of reaction times.

Treisman's (e.g. 1986; 1988; Treisman and Gelade, 1980) model would make very different predictions. In feature integration theory, patterns of reaction time are determined by whether the item to be identified is unique in a simple feature, or whether it is unique only in its arrangement of simple features. For simple feature stimuli, the effect of valid cuing of form information should be to facilitate identification of the target, since form information, but not location information, is primitively accessible for these stimuli. Thus an incorrect form cue could cause interference with the selection of the correct target item (since subjects will have to chose between two activated feature maps), whereas a valid form cue will cause no such interference. For more complex stimuli, there should be no preattentively accessible form information, and thus the effects of form cuing should be lessened or absent.

As well, feature integration theory predicts that correct location cuing should allow greater facilitation of identification for the complex stimuli than the simple stimuli, because, while the mechanism for feature registration may gain in accuracy through the orientation of spatial attention to a location (see Prinzmetal et al, 1986; Nakayama and Mackben, 1989), the discrimination of conjunction stimuli relies both on feature registration and on a spatially indexed, feature conjoining mechanism. In this cuing experiment then, one would predict from feature integration theory a three way interaction of form cuing, location cuing, and item type. For simple items, correct form cuing given correct location cuing should yield about the same benefit as correct form cuing given incorrect location cuing; for complex items, correct form cuing should be more beneficial than incorrect form cuing, given correct location cuing, but result in equal reaction times for an incorrect location cue, since subjects would have to restart processing at a new location.

To test these opposing predictions, the experiment described above was carried out. Subjects were presented with a peripheral location cue that was also a cue as to the form of a subsequent target, which they were to rapidly identify. In an effort to discriminate between feature integration theory and similarity theory, two kinds of target items were used: simple features and feature conjunctions. A neutral condition was also included in order to measure the facilitory or inhibitory effects of cuing.

METHOD

Subjects

Thirty six subjects served in the experiment. All were undergraduates at the University of Alberta, and participated in exchange for course credit. All subjects had normal or corrected to normal vision.

Stimuli

Figure 1 illustrates the stimuli used in this experiment. All stimuli were drawn within a square that subtended 0.31° by 0.31° visual angle. The simple set of items (Figure 1a) were diagonal lines of 45° and 135° orientation. The complex set of items (Figure 1b) were a lower case "H" shape, and a four shape. These feature conjunctions had an equal number of horizontal and vertical lines segments, and differed only in the arrangement of these lines.

A masking stimulus was also used in the experiment, and is illustrated in Figure 1c. It can be thought of as all of the complex and simple stimuli overlapped spatially, or as an outline square, open at top and bottom, with both diagonals drawn in, and with a horizontal line, perpendicular to the sides, drawn so as to intersect the "X" formed by the diagonals.

There were eight possible locations where stimuli could appear. They were distributed in a circle around the fixation cross, at a radius of 1.64° visual angle from fixation (see Figure 2). The ratio of size to retinal eccentricity was therefore approximately 1/5 for all stimuli.

Figure 1: Stimuli used in the experiments

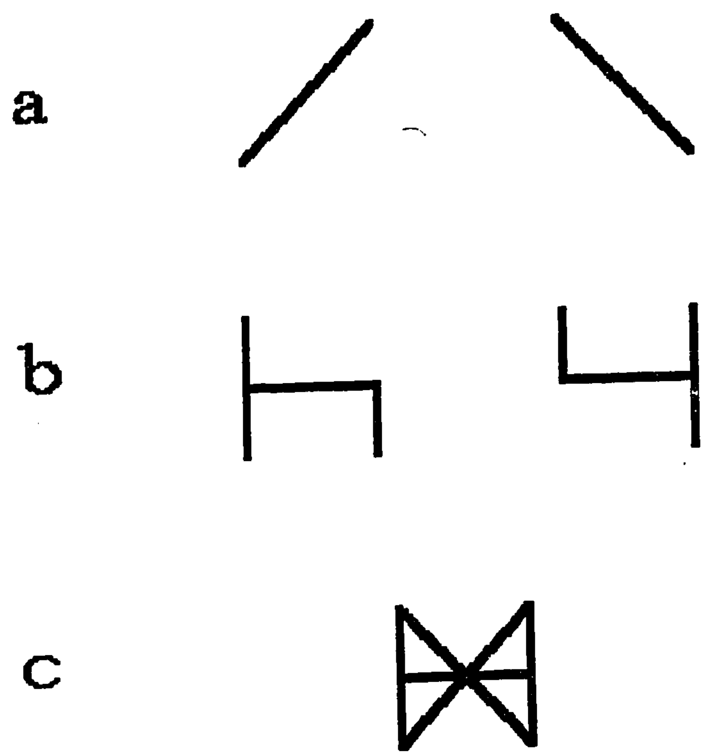
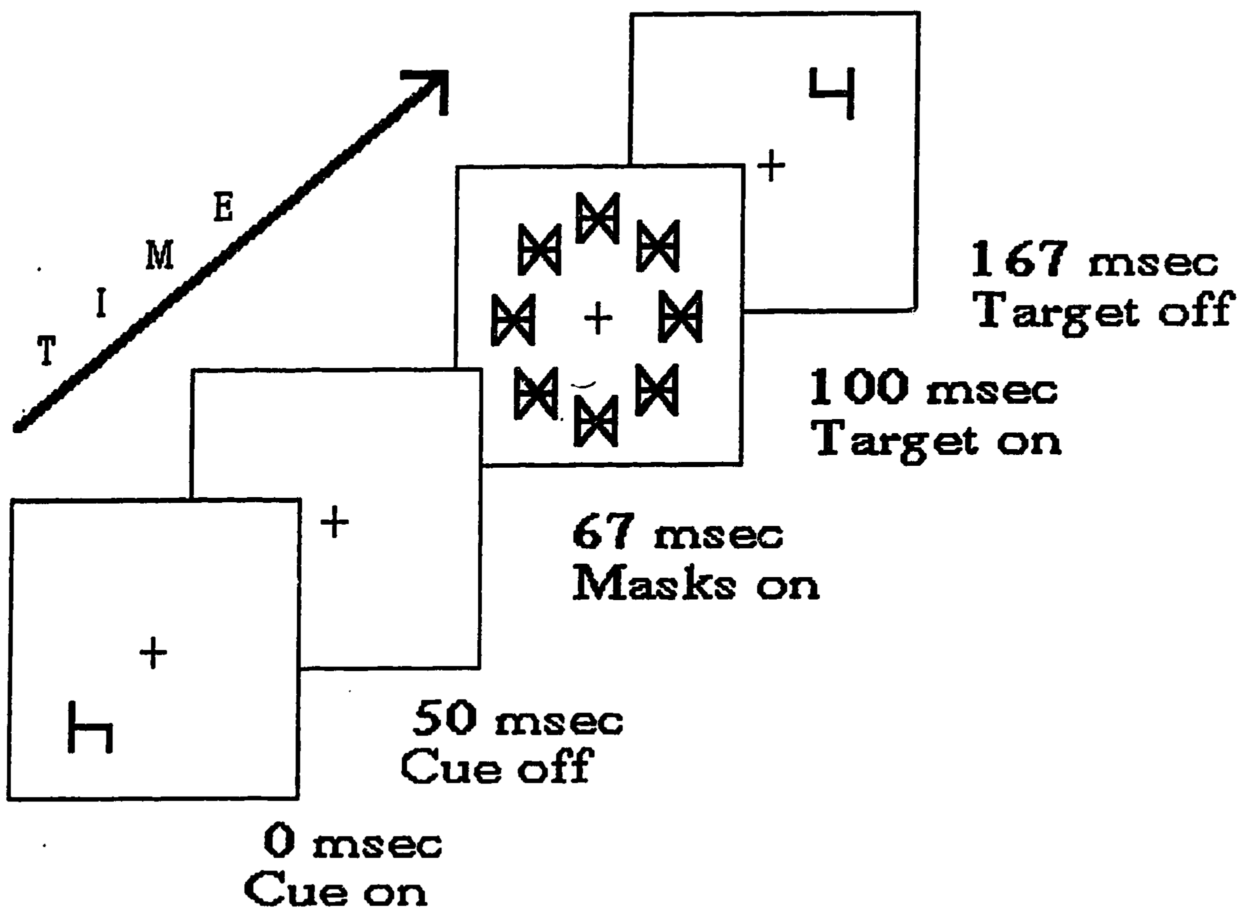


Figure 2: Time course of trials



Procedure

Stimuli were presented on a computer screen, in a dimly illuminated room. The luminance of the display background was 96 cd/m2, and the stimuli appeared in black with a luminance of 0.65 cd/m2, measured with a spot photometer. A central fixation cross remained on the screen throughout the trials. During the experiment, subjects sat with their chin resting on a chin rest to maintain a constant viewing distance of 1.85 meters. Subjects indicated their responses by button press, with one response mapped to each index finger. Stimulus presentation and response recording were performed by a Commodore 64 computer, using hardware interrupts as described in Wright and Dawson (1988).

Data was collected in two blocks of 160 trials, one block for each set of item type. To provide subjects with experience on the task, each block was preceded by 80 trials of practice. The order of blocks was randomly determined, with half the subjects receiving the simple stimuli first. On each trial, subjects received a tone 1.5 seconds before the presentation of the stimuli. The temporal order of displays is diagrammed in Figure 2. The cuing stimulus appeared at any one of the eight locations, and could be either of the two possible items for that set (i.e. either diagonal line, for the simple set; either an "H" or a four for the complex set). The cue remained on screen for 50 msec, and was followed by a blank screen (ISI) of 16.67 msec. Following the interval, masks appeared at all eight locations for 33.33 msec. Upon the offset of the masks, the target item was displayed for a duration of 66.67 msec. The target item occurred at either the same or the opposite location as the cue, and could be either one of the items from that set. The location of the target, and its form, were determined randomly.

Four fifths of the trials followed the pattern above. The remainder of the trials were neutral trials, where no cue was presented. On neutral trials, the cue was replaced by eight small dots, one at each possible target/cue location. The five conditions of the experiment are diagrammed in Figure 3, for an "H" as the target item. Each condition was replicated twice at each possible location of target, and once for each possibletarget item. The same conditions were used for the simple items.

The main dependent measure was reaction time to make a decision, although error rates were also analyzed. It was assumed that the mapping of responses to hands would not cause any effect in reaction times. However, subject's response mappings were counterbalanced into two groups, left hand responds to four and a 135° line or left hand responds to "H" and a 45° line. This factor, along with the two possible orders subjects could receive stimuli in, were varied as between subject factors. Hand mappings were counterbalanced across subjects, as was the order of presentation of the stimuli sets.

RESULTS

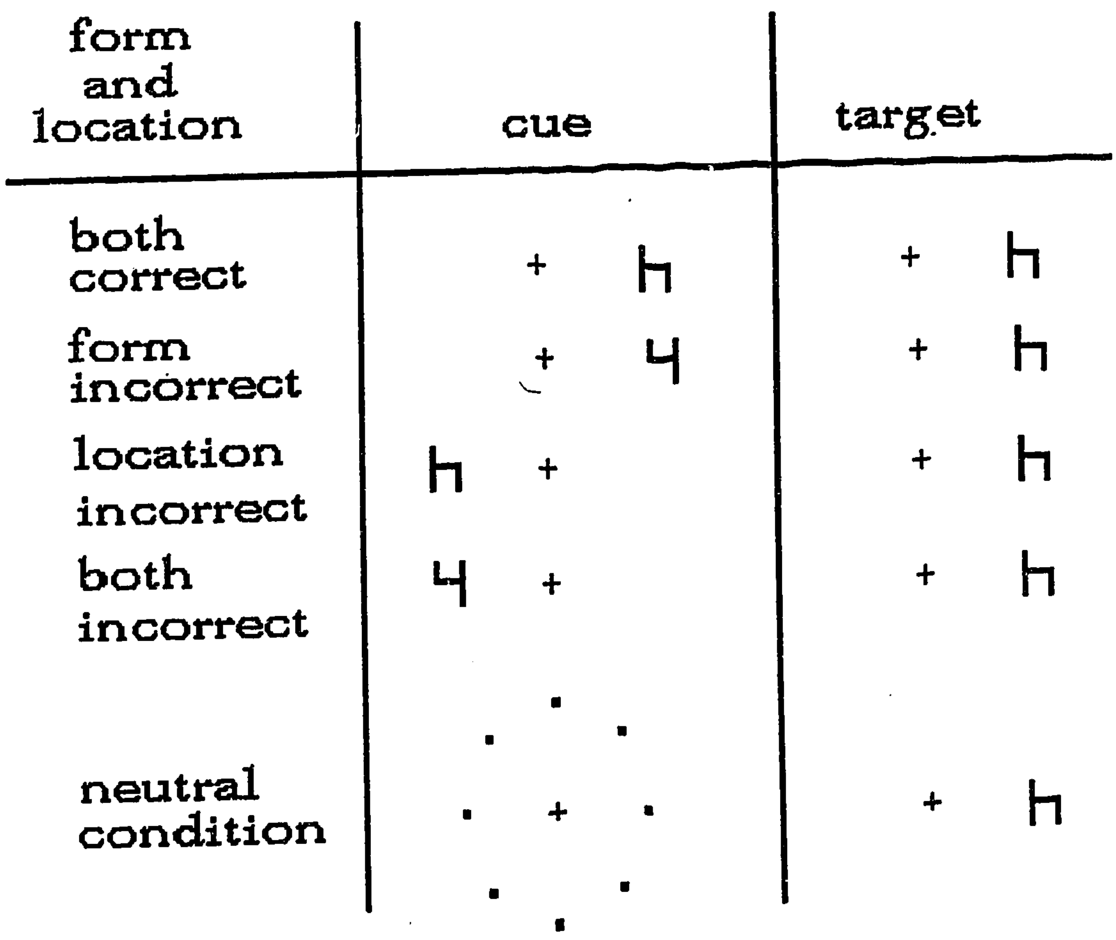
Data summarization

Mean reaction times were determined for each subject in each condition. A trial was excluded from the calculation of a subject mean if the subject made an incorrect response, or if the RT was deemed to be an outlier. Removing outliers is an established procedure (see Duncan, 1989; Duncan and Humphreys, 1989; Treisman and Gormican, 1988, for examples), whose purpose is to make the data more closely resemble a normal distribution, thereby increasing the power of the statistical tests. A reaction time was considered an outlier if it was more than two standard deviations larger or smaller than the grand mean for the individual subject, calculated separately for each item type. These restrictions resulted in 1.82% of the data points being excluded. Appendix A gives the distribution of outliers across conditions for both experiments.

Between subject analysis

The two effects of the between subject factors, the mapping of stimuli to hands and the order of presentation for the kind of

Figure 3. Examples of trial types



stimuli, were tested with a two factor analysis of variance (ANOVA). The main effect of hand mapping failed to reach significance [$F(1,32) = 3.00$, $p > 0.05$], and the F-ratios for the main effect of order and for the interaction term were less than one. The tests indicate these two control variables have no effect on the reaction times. Thus, in subsequent analyses these two variables were collapsed.

<u>Within subjects analysis</u>

To test the effects of cuing relative to a baseline condition, each subject's neutral condition RT's were subtracted from the values observed for their relevant item type condition (see footnote 1). After collapsing the between subject factors and subtracting the subject's neutral conditions, there are three within-subject factors, each with one degree of freedom: location cue validity (correct vs incorrect), form cue validity (correct vs incorrect), and item type (simple vs complex). The analysis was treated as a within-subjects RBF design with 35 degrees of freedom in the error terms (see Kirk, 1982, for a description of the RBF design). In order to see if the pooling of error terms was advisable (as in Kirk, 1982), an F-max test was conducted (Edwards, 1985). The observed F was large enough to indicate that the pooling of error terms was not advisable [$F(35,35) = 21.55$, $p < 0.05$]. The overall uncorrected mean RTs for subjects are presented in Table 1. Relative RTs for each condition are presented in Table 2. Negative numbers represent facilitation relative to the respective neutral.

Tests of the main effects revealed a significant location cuing effect (-13 msec correct cue vs 35 msec incorrect cue, $F(1, 35) = 103.13$, $p < 0.05$), and a significant main effect of form cuing (-9 msec correct cue vs 30 msec incorrect cue, $F(1,35) = 47.57$, $p < 0.05$). The main effect of item type was not significant in this analysis (mean relative RTs of 16 msec for simple items, and 5 msec for complex items).

The test of the interaction between item type and location cuing

Table one: Mean unadjusted RTs for all conditions

	Item type: SIMPLE		COMPLEX	
	Correct Location	Incorrect Location	Correct Location	Incorrect Location
Correct Form	529 msec[a] (88 msec)[b]	582 msec (87 msec)	560 msec (107 msec)	614 msec (108 msec)
Incorrect Form	557 msec (92 msec)	606 msec (98 msec)	622 msec (96 msec)	657 msec (98 msec)
Neutral Cue	552 msec (93 msec)		607 msec (103 msec)	

a Mean reaction time

b Standard deviation of the mean

Table two: Mean RTs adjusted for neutral condition

	Item type: SIMPLE		COMPLEX	
	Correct Location	Incorrect Location	Correct Location	Incorrect Location
Correct Form	-23.7 msec[a] (30 msec)[b]	30.1 msec (49 msec)	-48.1 msec (36 msec)	6.2 msec (48 msec)
Incorrect Form	4.5 msec (30 msec)	53.1 msec (66 msec)	14.1 msec (44 msec)	49.4 msec (48 msec)

a Mean reaction time

b Standard deviation of the mean

was non-significant, indicating no reliable difference in relative RT due to location cuing over item type [$F(1,35) = 0.64$]. The interaction between location cuing and form cuing did, however, reach significance [$F(1,35) = 4.58$, $p < 0.05$]. Post-hoc Scheffe comparisons, protected at the 0.05 level, were conducted on the cell means collapsed over stimulus type. These tests indicated a significant difference between correct and incorrect form cues, given an incorrect location cue (18 msec correct form cue, 51 msec incorrect form cue, Scheffe's F = 73.877, significant for the comparison F (F') of 4.12). Also, the conditions of correct location cue with incorrect form cue and correct form cue with incorrect location cue, were significantly different (9 msec and 18 msec respectively, Scheffe's F = 5.24 for F' = 4.12). Tests of the effect of location cuing showed a significant difference between correct and incorrect location cues when form cuing was incorrect (18 and 51 msec respectively, Scheffe's F = 118.45), and when form cuing was correct (- 35 msec and 9 msec respectively, Scheffe's F = 193.45).

The interaction between form cuing and item type reached significance [$F(1,35) = 14.09$, $p < 0.05$]. Scheffe post-hoc comparisons indicated no significant differences between the means of the simple and complex items when form cuing was incorrect (29 msec and 31 msec respectively, Scheffe's F = 0.31; F' = 4.12). Correct form cuing for the simple items was significantly faster than the two incorrect form cuing conditions (3 msec relative RT for simple items, Scheffe's F = 35.16), and the relative RT was not significantly different from zero (Scheffe's F less than one). Correct form cuing for the complex (h and four) stimuli was significantly faster still (-21 msec relative RT, Scheffe's F = 22.54 for the comparison of the h and four stimuli to the simple items, correct form cuing condition; F = 82.41 for the comparison with the incorrect form cuing means).

The three way interaction failed to reach significance [$F(1,35) = 1.99$, $p = 0.16$]. Therefore, the interaction terms need not be interpreted in terms of this higher level interaction.

<u>Analysis of errors</u>

The average number of errors for all subjects in each condition is presented in Table 3. A within-subjects ANOVA was used to test the means for any indication of a speed-accuracy trade off. The same statistical design was used on the error means as had been used on the RT's. Two effects were significant, the effect of form cuing [$F(1,35) = 6.89$, $p < 0.05$], and the main effect of item type [$F(1,35) = 29.05$, $p < 0.05$]. The main effect of location cuing was non-significant [$F(1,35) = 2.69$, $p < 0.05$]. Examination of the means, in those conditions where there was a significant difference, indicated that the pattern of errors follows that of the reaction times. Higher errors occurred in those conditions that also led to longer reaction times: invalid form cues or complex items. No interaction term was significant.

DISCUSSION

The results of the experiment are consistent with similarity theory (Duncan and Humphreys, 1989), and are inconsistent with feature integration theory (Treisman, 1988). First, both cuing of location information affected response latencies, by about the same amount, for both types of stimuli. Relative to the neutral condition, correct location cues resulted in an RT facilitation of 13.3 msec, and incorrect location cues slowed RTs by 34.7 msec. That these two effects are observed for both simple and complex items supports Duncan and Humphreys' (1989) proposal that location is coded in the representation of both item types.

Second, and also consistent with the predictions of similarity theory (Duncan, 1980; Duncan and Humphreys, 1989), cuing of form information affected response latencies. Again this was true for both simple and complex items. Correct form cues facilitated response latencies by 9 msec, and incorrect form cues slowed reaction times by 30 msec, relative to the neutral conditions. However, the significant form cuing by item type interaction showed that the effects of form cuing varied over item type. An

Table three: Error rates for all conditions

Item type:

	SIMPLE		COMPLEX	
	Correct Location	Incorrect Location	Correct Location	Incorrect Location
Correct Form	2.2%[a] (2.61%)[b]	4.7% (5.5%)	4.2% (4.1%)	5.2% (5.0%)
Incorrect Form	3.9% (5.8%)	6.9% (5.8%)	8.9% (6.8%)	8.4% (7.8%)
Neutral Cue	4.0% (4.7%)		6.1% (4.8%)	

a Mean percentage errors

b Standard deviation of the mean

examination of the relative RTs demonstrates that both simple and complex items are slowed by incorrect form cues, and by about the same amount (about 29 and 31 msec respectively, not significantly different). In contrast, the complex items show a facilitation in RT of about 21 msec when given correct form cues, but the simple items show no effect of valid form cuing (relative RT of about 3 msec, not significantly different from zero).

This difference in facilitation between the two item types can be accounted for by a floor effect for the processing of simple items. The unadjusted reaction times show that there is a main effect of item type (see footnote 1), which is eliminated when the relative RTs are calculated. In the unadjusted data, simple items are processed significantly faster than complex items (mean RT 568 msec for simple items, 613 msec for complex items). Because they are being processed more rapidly than complex items, simple items might already be processed as rapidly as possible. Thus, incorrect form cuing can affect the simple items by slowing processing, but correct form cuing may not facilitate their processing beyond their present speed.

Relation to Previous Results

Other research on visual attention has produced results similar to those reported above. For example, the difference between the means of valid and invalid location cuing conditions is of the same size as the effects found by Briand and Klein (1987, Experiment 4). Briand and Klein used valid, invalid and neutral peripheral location cues, without accompanying form cues, to examine feature integration. Subjects decided whether a set of two letters, presented to either the left or right of a fixation point, contained an R. Subjects were precued with the probable location of the target stimuli. The question of interest was whether correct location cuing would reduce reaction times to decide if an R was absent, in conditions that could lead to the creation of illusory conjunctions (Treisman and Gelade, 1980; Treisman and Schmidt, 1982; Treisman and Patterson, 1984). When the letters PQ were presented a total difference of 48 msec was found between correctly and incorrectly cued locations. Briand and Klein (1987) interpreted this to indicate that attention was required to prevent the generation of an illusory "R" from the letters PQ. Relative to their neutral condition, the facilitation due to location cuing was slightly larger in their experiment (22 msec) while the inhibitory effect was slightly smaller (26 msec, both values estimated from Briand and Klein, 1987, figure 5) than the effect in Experiment I. When a set of letters were used such that no illusory conjunctions could be generated from the target absent displays (ie the letter set RPB, for which the absent condition is PB) there was an overall cuing effects of only 19 msec. The differences between valid and invalid location cuing, reported here for both the simple and the complex items, are in the range of Briand and Klein's results for conjunction stimuli. It should be noted that Briand and Klein ran their feature (PB) and conjunction (PQ) conditions between subjects. In terms of similarity theory, since the target templates were not equated across conditions, it would be possible for subjects in the feature condition to efficiently exclude the PB stimuli pair from access to VSTM. Subjects in the conjunction condition would not be able to efficiently exclude the PQ stimuli from VSTM, because of the more complex target template required. Were Briand and Klein's feature condition and conjunction condition run in mixed blocks, or the stimuli modified as in Duncan and Humphreys's (1989) Experiment 5, one would expect there to have been equal effects of location cuing in both of their conditions.

The main effects of the form cuing reported in Experiment I, for both simple and complex stimuli, are also consistent with the size of priming effects reported in the literature. For example, Tipper (1985) has reported effects ranging from a facilitation of 80 msec to a slowing of 51 msec (Experiment 2), in studies of the effects of repetition priming by unattended pictorial stimuli. Similarly, Miller (1987) reports priming effects ranging up to 60 msec for the difference between valid and invalid cues, in a letter identification task where correct response categories were primed by letters that flanked a target letter.

One advantage of the current experiment over the work cited above is that its experimental design permits the examination of interactions between types of cuing. The significant interaction between form and location cuing in Experiment I indicates that the effects of these factors are <u>not</u> independent (additive). If either form or location cuing, but not both, are invalid, then there is a small (but significant) slowing of reaction time, relative to the neutral condition (9 msec for correct location cue, incorrect form cue and 18 msec for correct form cue, incorrect location cue). If both form and location cuing are correct, however, there is a facilitation in RTs of 35 msec, relative to the neutral. If both form and location cuing are incorrect, RTs are slowed by 52 msec, relative to the neutral. This particular pattern of interactions is consistent with similarity theory (Duncan and Humphreys, 1989). In the theory, both location and form information is encoded at the same locus in processing, so one would expect their effects to be dependent (interactive) rather than independent (additive).

The form cuing by location cuing interaction is consistent with the findings of Muller and Rabbitt (1989), who looked at the relationship of form and location information in directing attention. In their task, subjects were given a clearly discriminable target (a T in one of four different orientations) and a precue as to the probable location of a briefly presented comparison item (another oriented T). Subjects reported both the location and the form of the test stimulus (by a same/different response). The dependent measures were the conditional probabilities of the possible combinations of correct and incorrect location and form responses. Muller and Rabbitt found that the probability of a correct form response, given an incorrect location report, exceeded chance, as did the probability of a correct location report, given an incorrect form response. Such a result is not consistent with a theory where stimuli must be localized before they are identified, but is consistent with a theory in which both form and location information can direct access to processing (Duncan and Humphreys, 1989; Muller and Rabbitt, 1989).

Similarly, Posner et al (1980) report a cuing experiment in which subjects were given centrally presented cues about the form and location of a peripherally appearing target letter. Location was cued by presenting an arrow, pointing to the left or right, just above fixation. The neutral location cue was a cross. The form of the target was cued by presenting the probable target letter below the location cue. Again, the difference between valid and invalid location cues conditions was about 48 msec. Correct location cues facilitated reaction times by about 17 msec, relative to a neutral condition, while incorrect location cues resulted in a slowing of approximately 31 msec (Posner et al, 1980, Table 1). In contrast to the results of Experiment I, however, there was no effect of form cuing, nor any tendency towards an interaction of location cuing and form cuing. The lack of a form effect could be accounted for by low target discriminability, the use of difficult to differentiate target letters or, perhaps, differences between peripheral cuing, used in Experiment I, and central cuing (See Jonides, 1981).

The results of Lambert and Hockey (1986, experiment one), suggest Posner et al's (1980) failure to find an interaction effect of location and form cuing was most likely due to their choice of stimuli. Using simple and highly discriminable stimuli, Lambert and Hockey found effects of central cuing with combined cues of the expected target's location and form. Here, subject's task was to identify the orientation (vertical or horizontal) of a geometric figure (either an ellipse or a rhombus) presented to the left or right of fixation. Valid, invalid or neutral cues to the probable location and form of the target item were presented at fixation for 600 msec before the target appeared. Subjects participated in four blocks of trials. In the last two blocks of trials subjects were instructed to use either location or form cues alone, although both kinds of cues were still presented. Valid and invalid form cuing yielded significant effects in the first block and in the attending to form cuing alone conditions, but not in the second block or the attending to location only condition. Valid and invalid location cues yielded significant effects in all blocks and conditions. The difference between correct and incorrect form cues, when they occurred, were between 13 to 30 msec (estimated from Lambert and Hockey, 1986, figure 3). Valid and invalid location cues differed by about 50 msec, except in the condition where subjects attended to form cuing alone, where they differed by about 30 msec.

Taken together, the results of Posner et al (1980) and Lambert and Hockey (1986) suggest that, for central cuing, attentional selection can proceed on the basis of form information, provided that the target items are sufficiently discriminable. However, location cuing has a more reliable effect, as suggested by Duncan (1981). Experiment I demonstrates that effects of form cuing can occur with entirely peripheral cuing of form. Further, the effect was obtained when correct and incorrect cues, for both location and form, were equiprobable (see footnote 2). The results show that the effects reported by Lambert and Hockey (1986) and Muller and Rabbit (1989) do occur with peripheral cuing of form, and are similar for stimuli sets equated in terms of simple features (Experiment I's complex items) and those that are not (Experiment I's simple items). Their results, and those of Experiment I, support similarity theory's (Duncan and Humphreys, 1989) assumption of a common coding of form and location information at an early, preattentive, level of processing.

nconsistencies with Feature Integration Theory

In contrast, feature integration theory (Treisman, 1988) is not supported by the results of Experiment I. Patterns of reaction times contradicting those predicted by feature integration theory appear in both the simple and complex item conditions. For the simple items, the differences between correct and incorrect location cuing, across both levels of form cuing, is significant (evaluated in terms of a t value, the differences are significant for correct and incorrect form cuing, [$t(70) = -2.55$, $p < 0.05$ and $t(70) = -2.17$, $p < 0.05$] respectively). This is inconsistent with an account which suggests that form information for simple features, such as line orientations, is accessible independent of location information (Treisman, 1986; 1988; Treisman and Gelade, 1980).

For the complex items, feature integration theory proposes that the constituent line arrangements of stimuli like the h and four shapes should only be recoverable after the interrogation of an object file. A new file is set up for each object upon its appearance (Khaneman and Treisman, 1984; Khaneman, Treisman and Burkell, 1983), and one function that object files serve is the segregation of perceptual entities. Thus feature integration theory predicts that invalid cuing of location should result in the elimination of form cuing effects, for complex items. However, evaluation of the difference between correct and incorrect form cuing, given incorrect location cuing, shows a significant difference. The difference indicates that the processing of two items 3.28 degrees apart was not independent, as the object files account requires.

The weak predictions of feature integration theory are also not supported by the pattern of interactions revealed in Experiment I. There is no interaction between item type and location cuing, as one would expect (Briand and Klein, 1987; Treisman and Gelade, 1980). Further, the three way interaction predicted by feature integration theory failed to reach significance ($p = 0.16$). However the largest effect of form cuing was found in the complex item, correct location condition (an approximate difference in means of 62 msec). Had the difference between valid and invalid form cues, given incorrect location cues, for the complex items been equal to the same difference for the simple items, the interaction might have reached significance. Since there was a weak tendency for the data to approach a three way interaction, a replication of the experiment was in order, eliminating one factor that could have weakened this possible interaction.

One aspect of the design which could have mitigated the three way effect is the neutral cuing condition. This condition could have affected the response times, either by perturbing the calculations of the relative RTs, or by having differential effects on the simple and complex conditions. Relative RTs were calculated by subtracting each subject's mean score on the particular item type's neutral condition from the RTs of that item type's other conditions. Naturally, each subject's RTs for the neutral condition will contain some random variations, error that is not correlated with any other subject's error. It is possible that this random variation in the neutral condition for each subject introduced sufficient variation in the relative RTs to eliminate the three way interaction. One counter-argument against this proposal is that the unadjusted RTs for Experiment I do not show any effect that is not present in the adjusted RTs; the only difference between the two analyses is the presence of the item type effect in the unadjusted RTs.

A more troubling possibility is that the neutral condition might have had different effects on the simple and complex items, effects that are unrelated to the comparisons of interest. As Jonides and Mack (1984) point out, the logic behind the use of a neutral condition is that the neutral cue should require all the processing steps that the valid and invalid cues require, except for the steps of particular interest. In this experiment, the neutral condition should have had the same alerting functions as the cuing item, but should not have cued the target's location or form. While there is no apparent reason to doubt the validity of the neutral condition in this experiment, the conclusions drawn from Experiment I would be strengthened by eliminating any controversial aspects of the design. Jonides and Mack have suggested that when the test of a particular model depends upon the presence of differences between means, rather than relative RTs, neutral conditions should be avoided. Because the predictions of feature integration theory depend upon the existence or non-existence of differences between valid and invalid conditions, such as a main effect of location cuing for simple items, or the elimination of form cuing given incorrect location cuing for complex items, a replication omitting the neutral condition can provide an additional test of feature integration.

Experiment II was essentially a replication of Experiment I that excluded the neutral cuing condition. This allowed for the predictions of feature integration theory to be examined in a design which was (arguably) more likely to produce specific effects, such as a three-way interaction between item type, form cuing and location cuing, which were not observed in Experiment I.

EXPERIMENT II

METHOD

Subjects

Thirty six subjects, none of whom had participated in Experiment I, were recruited from the same pool of subjects. All had normal or corrected to normal vision.

Stimuli

The stimuli used in this experiment were the same as those used in Experiment I, with the exception that a neutral cuing condition was not used.

Procedure

The procedure closely followed that of Experiment I, except for the following changes. The total number of trials used in the data blocks were increased to 192. With the exclusion of the neutral condition, this lead to 48 replications of each of the four conditions. The total number of trials for the practice blocks was decreased to 64. Timing parameters, and all other aspects of the procedure were as in Experiment I.

RESULTS

Data summarization

The data was summarized as in Experiment I. Analyses were conducted on the mean reaction times for each subject in each condition. Removal of outliers resulted in the exclusion of 2.06% of the data points. See Appendix A for the distribution of outliers across conditions.

Between subject analysis

As in Experiment I, the two between subject factors, the mapping of stimuli to hands and the order of presentation for item type, were tested with a two factor ANOVA. The main effect of hand mapping again failed to reach significance [$F(1,32) = 2.69$, $p > 0.05$], as did the main effect of order of presentation [$F(1,32) = 2.97$, $p > 0.05$]. The F-ratio for the interaction term was less than one. Following the rationale of Experiment I, these two variables were collapsed in the subsequent analyses. As a result, the design was treated as an RBF within subjects design with 35 degrees of freedom in the error terms (Kirk, 1982). An F-max test (Edwards, 1985) again indicated that the pooling of error terms was not advisable [$F(35,35) = 54.43$, $p < 0.05$]. The overall means for subjects are presented in Table 4.

Within subjects analysis

As in Experiment I, the three within subject factors were location cue validity, form cue validity, and item type. For the cue validity factors, the levels are correct vs incorrect, for the factor of item type, the levels are simple stimuli (diagonal line) vs complex stimuli ("H" or four). An ANOVA on this design revealed that the main effect of form cuing was significant, with valid form cues leading to faster RT's than invalid form cues (600 msec vs 651, $F(1, 35) = 78.85$, $p < 0.05$). The main difference between valid and invalid location cuing was also significant, with valid cues giving faster reaction times than invalid location

Table four: Mean RTs for all conditions

Item type:

	SIMPLE		COMPLEX	
	Correct Location	Incorrect Location	Correct Location	Incorrect Location
Correct Form	540 msec[a] (128 msec)[b]	591 msec (126 msec)	599 msec (159 msec)	670 msec (148 msec)
Incorrect Form	572 msec (121 msec)	639 msec (150 msec)	671 msec (148 msec)	722 msec (164 msec)

a Mean reaction time

b Standard deviation of the mean

cues (596 msec vs 656, $F(1, 35) = 78.56$, $p < 0.05$). Item type also yielded a significant main effect, with reaction time to identify simple stimuli being faster than the reaction time to identify complex stimuli (586 msec vs 666 msec, $F(1, 35) = 9.20$, $p < 0.05$).

Both the interaction of location cuing with form cuing, and the interaction of location cuing with item type, failed to reach significance (both F's less than one). The effect of form cuing by type of item reached significance [$F(1, 35) = 6.00$, $p < 0.05$]. Scheffe comparisons indicated that the difference between correct and incorrect form cuing for simple items was significant (40 msec, $F = 43.541$, significant at $F' = 4.12$); as was the difference between correct and incorrect form cuing for complex items (62 msec, $F = 100.79$). The interaction effect indicates that the difference of these differences was significant. The three way interaction reached significance [$F(1, 35) = 5.82$, $p < 0.05$]. While the pattern of means seemed to indicate that form and location cuing interacted in both the simple and complex item conditions, Scheffe comparisons revealed no significant interaction for the simple items [$F = 2.40$], or the complex items ($F = 3.47$). Note that the form by location interaction for the complex items does approach significance ($p > 0.10$). That the two non-significant interactions are in the opposite directions accounts for the interaction. For simple items, the difference between correct and incorrect form cuing was largest under incorrect location cuing, but for complex items the largest difference between correct and incorrect form cues occurred under correct location cues. Tests on the difference between valid and invalid form cuing, given negative location cuing, revealed a significant difference for simple items (48 msec, $F = 45.69$), as well as a significant difference for complex items (52 msec, $F = 53.75$). For complex items, the effect of form cuing, given correct location cuing, was about 71 msec. For simple items, the difference was about 32 msec. The difference of these two differences was significant, with Scheffe's F = 14.50. Simple items showed an effect of location cuing. For simple items, the difference between valid and invalid location cuing was significant, for both valid form cuing (Scheffe's F = 51.67) and invalid form cuing conditions (F = 87.94).

<u>Analysis of errors</u>

The average number of errors for all subjects in each condition is presented in Table 5. A within-subjects analysis of variance indicated significant main effects for location cuing [$F(1,35) = 4.67$, $p < 0.05$], form cuing [$F(1,35) = 29.46$, $p < 0.05$] and item type [$F(1,35) = 4.86$, $p < 0.05$]. All of the main effects were in the direction of the RT data, with slower conditions showing higher errors. The interaction of item type with form cuing reached significance [$F(1,35) = 8.96$, $p < 0.05$]; again, the pattern followed the RT data. All the remaining interactions failed to reach significance (for the location by form cuing interaction, $F(1,35 = 1.81$, $p > 0.05$; for the three way interaction and the location by item type interaction, both F's less than one). Thus, analysis of the errors showed no indication of a speed accuracy trade off.

<u>DISCUSSION</u>

All of the main effects found in Experiment I were replicated in Experiment II. Location cuing, form cuing and item type all had significant effects, with the difference between correct and incorrect location cues averaging 60 msec, the difference between correct and incorrect form cues being about 51 msec, and complex items being slower than simple items by about 80 msec. The interaction of form cuing and item type was also significant in Experiment II, with the difference between correct and incorrect form cues being smaller for simple items (40 msec) than complex items (60 msec). Overall, these differences are slightly larger in Experiment II than the comparable differences in Experiment I, but show the same pattern.

The two experiments differed in two ways. The form by location

Table five: Error rates for all conditions

	Item type: SIMPLE		COMPLEX	
	Correct Location	Incorrect Location	Correct Location	Incorrect Location
Correct Form	3.9%[a] (4.1%)[b]	5.7% (5.0%)	5.2% (7.1%)	6.6% (5.5%)
Incorrect Form	6.4% (5.2%)	10% (9.5%)	11% (12.1%)	13.4% (11.2%)

a Mean percentage errors

b Standard deviation of the mean

interaction failed to reach significance in Experiment II ($p = 0.42$), but did reach significance in Experiment I. Also, the three way interaction between form cuing, location cuing and item type reached significance in Experiment II ($p = 0.02$), but not in Experiment I. An examination of the RT patterns in the three way term for Experiment II indicates that, while there is no significant interaction of form by location cuing for either the simple or complex item types, there is a tendency for each of the item types to approach a form by location effect. For the complex items, this effect is marginally significant ($p = 0.10$, by Scheffe's), and shows that correct location cuing leads to the largest form cuing effects. The pattern in the complex items is almost exactly that seen in Experiment I, for this condition, in the non-significant three way. For the simple items, the form by location effect is the opposite of that seen in the complex items, with incorrect location cuing leading to the greatest form cuing effect.

On the basis of the results of Experiment II, it seems that the results of Experiment I are robust. If the neutral condition in Experiment I had any differential effect on simple versus complex items, it mainly distorted the RTs observed in the simple item condition. Both experiments show that form and location information are encoded in the representations of <u>both</u> simple and complex items. Thus, the experiments support similarity theory (Duncan and Humphreys, 1989), and do not support feature integration theory (Treisman, 1988). The significant three way term allows a direct evaluation of the difference between correct and incorrect location cuing for simple items, and the difference between correct and incorrect form cuing, given incorrect location cuing, for complex items. For the simple items, the difference between correct and incorrect location cuing, was significant for both correct and incorrect form cuing (Scheffe's F being 51.67 and 87.94 respectively, both comparisons exceeding the appropriate F'). For the complex items, a test of the difference between form cuing means, given an incorrect location cue, was significant (Scheffe's F = 53.75). A significant result for any one of these comparisons is inconsistent with feature integration theory.

GENERAL DISCUSSION

The goal of Experiments I and II was to compare similarity theory with feature integration theory. Similarity theory (Duncan and Humphreys, 1989) proposes that both simple and complex item types are initially coded in a common format, the structural unit, and that this format encodes both the form and the location of a stimulus item. These claims lead to two predictions. First, the processing of simple and complex kinds of stimuli will be affected by both the form and the location of the briefly presented cue. Second, the effects of form and location cuing should be interactive, rather than additive, because of their common locus in processing. In contrast, feature integration theory (Treisman, 1988; Treisman and Gelade, 1980) predicts that there will be specific differences in the patterns of reaction times for simple items as opposed to complex items. In this theory, a simple item's form can be identified independently of location. While form cuing might effect the recognition of a simple items, valid and invalid location cuing should have no effect on its processing (Treisman, 1985). For complex items, form and location cuing should interact in such a way that there is no difference between the means of valid and invalid form cuing conditions when location cuing is invalid, but a large difference when location cuing is valid.

The two experiments support the claims of similarity theory (Duncan, 1981; Duncan and Humphreys, 1989). Processing of both simple and complex items was affected by valid and invalid cuing of form, and processing of both simple and complex items was affected by cuing of location. Further, the two-way interactions in Experiment I, and the three way interaction in Experiment II, show that location and form information do not have independent effects on processing. These interaction terms are consistent with a theory in which the coding of form and location information occurs at the same locus of processing for both types of stimuli (ie, similarity theory). These interaction terms are not consistent with a theory that proposes simple and complex items are recognised at different stages of processing (ie, feature integration theory).

Feature integration theory makes specific, independent, predictions about what the pattern of reaction times should be for simple items as opposed to complex items (Treisman, 1988; Treisman and Gelade, 1980). These predictions are not supported by the results of the two experiments. As noted above, feature integration theory predicts that location cuing should not have an effect on highly discriminable feature items (Treisman, 1986; 1988; Treisman and Gelade, 1980; Treisman and Gormican, 1988). However, in both experiments, the processing of the simple items is effected by location cuing. In the complex item condition, feature integration predicts that there should be no difference between the means for valid and invalid form cuing when location cuing is invalid. This prediction arises from the theory's assumption that the recognition of complex (conjunction) stimuli relies on the interrogation of an object file (Treisman, 1986; 1988). In terms of the object file account, if an object file were drawn to both cue and target, then there should be no carry over of processing. If an object file were drawn only to the target item, then again there should be no difference between correct and incorrect form cues, because the conjoined properties of the complex stimuli should not be recoverable from Stage 1 processes. However, the difference between valid and invalid form cuing is significant for complex items when an incorrect location cue is given. The processing of the cue at one location affected the processing of the target item at another, in contradiction to feature integration theory.

A number of alternative explanations of the effects inconsistent with feature integration theory can be rejected. For instance, to explain the location cuing effects for simple items one could suggest that spatially allocated attention was required to boost the discriminablity of the simple features. However, both experiments used stimuli quite large in relationship to their retinal eccentricity, so this alternative seems unlikely (see Briand and Klein, 1987; Prinzmetal et al, 1986 and Treisman and Gormican, 1988 for suggestions that attention facilitates feature registration). To explain the significant difference between valid and invalid form cuing of complex items, given invalid location cuing, for complex items, one could modify feature integration theory to permit preattentive detection of some complex items. Specifically, one might suggest that "feature detectors" for alphanumeric characters could evolve through practice with such tasks as reading (Treisman and Gelade, 1980; Treisman and Souther, 1986). According to this explanation, because the complex items in these experiments were alphanumeric symbols, subjects might be able to preattentively detect the identity of the characters (Treisman and Souther, 1986). Thus, one would expect form cuing effects for these stimuli because their detection is unmediated by an object file. Such an explanation, however, runs into difficulty explaining why using some high frequency English letters in search experiments, such as 'T' and 'L,' result in serial search effects (Beck and Ambler, 1973; Duncan and Humphreys, 1989). As well, this explanation is inconsistent with results that show that letter confusions are largely due to the failure to accumulate specific letter features (Dawson and Harshman, 1986).

Location cuing and spatial indexing

In addition to supporting the claims of similarity theory over those of feature integration theory, the results of both experiments are consistent with Pylyshyn's (1989) model of spatial indexing. Pylyshyn has proposed that the construction of a representation of an object from visual information requires the ability to index (tag, fix or "point to") locations in space. The purpose of this indexing is to individuate locations in the visual field, and to allow higher level, evaluative, processes (such as Ullman's (1984) visual routines) access to the form information at a location. Given these tasks, this indexing function must be independent of the information present at the tagged location. Further, these tags should not make the locations of the stimuli explicit to consciousness, but only serve as preattentive processing resource. In Pylyshyn's model, recognition depends upon higher level processes. The metaphor used to describe the indexing process is that it is like having one's finger resting on an object. This contact allows one to keep track of the object over its movements in space, and also enables one to direct further haptic explorations to the object, but need not, in itself, provide explicit form or location information. Pylyshyn extends the metaphor into the visual modality --the anacronym for the tokens that perform this indexing function, FINSTs, derives from the term FINger of INSTantiation -- and proposes that the total number of indexing tokens available to visual processes is limited.

For Experiments I and II, the FINST model predicts an effect of location cuing for both complex <u>and</u> simple kinds of items. For both kinds of stimuli, recognition of their form must be preceded by the assignment of a FINST to their location. On trials with valid location cues, a token will already be assigned to the correct location, and the evaluation of the target can proceed. On trials with invalid location cues, a FINST will be assigned to the wrong location. The FINST will have to be reassigned to the correct location, or a new FINST assigned, before evaluation leading to recognition, can proceed. As shown by the effects of location cuing in both experiments, valid location cues always result in faster reaction times to identify the target item than invalid cues. The location cuing results are consistent with the FINST model.

Although the location cuing results are consistent with the

FINST model, it does not (in its current form) account for the form cuing effects. Since the indexing of locations is the main concern of the hypothesis, the processes that register form are not fully detailed. However, the assignment of FINSTs occurs after such processes as feature registration and motion correspondence. As currently constructed, the FINST hypothesis can account for the canonical data of feature integration theory, such as illusory conjunctions and the pop out effect in visual search, but by different mechanisms (See Pylyshyn, 1989). In its current expression, however, no commitments are made to the process of complex form recognition. Pylyshyn suggests that complex form descriptions could be constructed piecemeal, through a recursive process. Another possibility is the application of visual routines, as described by Ullman (1984), to the feature information registered at Stage 1. If the FINST model is to account for the form cuing results observed in the two experiments, then it must be assumed that FINSTs represent some figural information about indexed objects, or that some spatial relations are computed by visual routines automatically and immediately after FINSTs are assigned.

Preattentive semantic access

These experiments tested one assumption of similarity theory, that complex form information, such as the line arrangements, and location information is encoded in a common format. While the data allows one to reject certain assumptions of feature integration theory (e.g. qualitatively different recognition processes for feature and conjunction stimuli), in favor of the assumptions of similarity theory, it should be noted that there are assumptions of the similarity theory framework that are not tested here. These experiments show that the holistic property of line arrangement is preattentively represented. However, these experiments do not necessarily show preattentive access to the semantic, or symbolic, information that the complex items represent. The effects reported here could be entirely due to the preattentive pick-up of the line arrangements in the complex items. Such preattentive detection of line arrangements is inconsistent with feature integration, but could be consistent with a preliminary stage of processing that outputs a relatively complete representation of the physical properties of the visual world. An example of such a complete representation would be the 2 1/2 - D sketch of Marr and Nishihara (1977), which encodes depth and orientation information across the visual field, or a version of Duncan and Humphreys's (1989) theory where only physical properties of the stimuli are operated over during Stage 1. Attention would then serve not to conjoin features, but to retrieve information from the base representation computed by low vision processes.

While these experiments have not tested similarity theory's assumption of preattentive semantic access, Duncan, too, has yet to empirically test similarity theory's claim that preattentive semantic access occurs (Duncan, 1989; Duncan and Humphreys, 1989). Current tests of the theory have focussed on physical similarity relationships, rather than semantic ones. In the literature, some effects that support the notion of preattentive semantic access have failed replication (Duncan, 1983), or can be explained through methodological flaws in those experiments that report them (see Holender, 1986, for a review), leaving the question of preattentive semantic access an open one. An alternative to supporting the whole similarity theory framework is to endorse a more limited version of the theory, one that suggests the stage of perceptual description operates only over physical properties of the information that can be directly transduced from stimuli on the retina. Selection to VSTM could then proceed on any physical property of the stimulus that can be represented at Stage 1.

CONCLUSION

The experiments reported here examined the claims of two theories of preattentive processes: Duncan and Humphreys' (1989) similarity theory and Treisman's (1988) feature integration theory. Similarity theory's claim that the holistic properties of objects are represented at the preattentive level was contrasted, in two experiments, with feature integration theory's claim that only simple feature information is represented at the preattentive level. Comparisons of the effect of valid and invalid cuing of subjects with the expected form and location of a target item supported the assumptions of similarity theory. Simple (feature) and complex (within item conjunction) stimuli are not processed in a qualitatively different fashion. The processing of both is affected by cuing of form and the cuing of location. The data support a version of similarity theory where at least the holistic physical properties of stimuli are encoded at the preattentive level.

FOOTNOTES

1 An analysis was conducted on the unadjusted reaction times, to determine how adjusting the RT's with the neutral conditions would effect the pattern of reaction times. This analysis entirely excluded the neutral conditions from consideration. The design of the analysis was also collapsed over hand mappings and orders of presentation, giving a within-subjects design with three two-level factors. The results of the two analyses differed only in a significant main effect of item type [$F(1, 35) = 13.54$, $p < 0.05$] being present in the unadjusted RTs. This effect was not present in the analysis for the adjusted RTs [$F(1, 35) = 2.10$, $p > 0.05$]. The main effect in the first analysis was due to the mean reaction time for simple items (572 msec) being faster than the mean reaction time for complex items (610 msec). The removal of the main effect in the second analysis is consistent with the use of a valid neutral cue (the difference between the mean for simple items, 16 msec, and zero was significant (Scheffe's $F = 4.70$ for $F' = 4.12$), but not the difference between the two item types). For the sake of brevity, only the analysis of the adjusted RT values is presented.

2. Posner et al (1980) and Lambert and Hockey (1986) manipulated the probability of cue validity to manipulate attention, making valid cues more likely than invalid cues.

REFERENCES

Beck, J. and Ambler, B. (1973). The effects of concentrated and distributed attention on peripheral acuity. Perception and Psychophysics, 14, 225-230.

Briand, K. and Klein, R. (1987). Is Posner's "beam" the same as Treisman's "glue"?: On the relation between visual orienting and feature integration theory. Journal of Experimental Psychology: Human Perception and Performance, 13, 228-241.

Broadbent, D. (1982). Task combination and selective intake of information. Acta Psychologia, 50, 253-290.

Dawson, M. and Harshman, R. A. (1986). The multidimensional analysis of asymetries in alphabetic confusion matrices: Evidence for global-to-local and local-to-global processing. Perception and Psychophysics, 40, 370-383.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. Psychological Review, 87, 272-300.

Duncan, J. (1981). Directing attention in the visual field. Percpetion and Psychophysics, 30, 90-93.

Duncan, J. (1983). Category effects in visual search: A failure to replicate the "oh-zero" phenomena. Perception and Psychophysics, 34, 221-232.

Duncan, J. (1985). Visual search and visual attention. In M. I. Posner & & O. S. Marin (Eds.), Attention and Performance XI (pp 205-219). Hillsdale, NJ: Erlbaum.

Duncan, J. (1989). Boundary conditions on parallel processing in human vision. Perception, 18, 457-469.

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

Edwards, A. L. (1985). Experimental Design in Psychological Research. New York: Harper & Row.

Eriksen, C. W. and Hoffman, J. (1973). Selective attention:

Noise suppression or signal enhancement? Bulletin of the Psychonomic Society, 4, 587-589.

Hoffman, J. E. (1978). Search through a sequentially presented visual display. Perception and Psychophysics, 23, 1-11.

Hoffman, J. (1979). A two-stage model of visual search. Perception and Psychophysic, 25, 319-327.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. Behavioral and Brain Sciences, 9, 1-66.

Houck, M. R. and Hoffman, J. E. (1986). Conjunction of color and form without attention: Evidence from an orientation-contingent color after-effect. Journal of Experimental Psychology: Human Perception and Performance, 12, 186-210.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye movement. In J. Long & A. Baddeley (Eds.), Attention and Performance IX (pp. 187-203). Hillsdale, NJ: Erlbaum.

Jonides, J. and Mack, R. (1984). On the cost and benefit of cost and benefit. Psychological Bulletin, 96, 29-44.

Khaneman, D. and Treisman, A. (1984). Changing views of attention and automaticity. In R. Parnassum (ed), Varieties of Attention. New York: Academic.

Khaneman, D., Treisman, A. M. and Burkell, J. (1983). The cost of visual filtering. Journal of Experimental Psychology: Human Perception and Performance, 9, 510-522.

Kirk, R. E. (1982). Experimental Design: Procedures for the Behavioral Sciences. Belmont, CA: Wadsworth.

Lambert, A. and Hockey, R. (1986). Selective attention and performance with a multidimensional visual display. Journal of Experimental Psychology: Human Perception and Performance, 12, 484-495.

Marr, D. and Nishihara, H. K. (1977). Representation and recognition of the spatial organisation of threedimensional shapes. Proceedings of the Royal Society of London B, 200, 269-294.

Miller, J. (1987). Priming is not necessary for selective-attention failures: Semantic effects of unattended, unprimed letters. Perception and Psychophysics, 41, 419-434.

Muller, H. J. and Rabbitt, P. M. A. (1989). Spatial cueing and the relation between the accuracy of "Where" and "What" decisions in visual search. Quarterly Journal of Experimental Psychology, 41A, 747-773.

Nakayama, K. and Mackben, M. (1989). Sustained and transient components of focal visual attention. Vision Research, 29, 1631-1647.

Neisser, U. (1967). Cognitive Psychology. New York: Appleton-Century-Crofts.

Palmer, S. E. (1977). Hierarchical Structure in Perceptual Representation. Cognitive Psychology, 9, 441-474.

Posner, M. I., Snyder, C. R. R., and Davidson, B. J. (1980). Attention and the detection of signals. Journal of Experimental Psychology: General, 109, 160-174.

Prinzmetal, W., Presti, D. E., and Posner, M. I. (1986). Does attention affect visual feature integration? Journal of Experimental Psychology: Human Perception and Performance, 12, 361-369.

Pylyshyn, Z.W. (1984). Computation and Cognition. Bradford. MIT press: New York.

Pylyshyn, Z. W. (1989). The role of location indexes in spatial perception: A sketch of the FINST spatial index model. Cognition, 32, 65-97.

Tipper, S. (1985). The negative priming effect: Inhibitory priming by ignore objects. Quarterly Journal of Experimental Psychology, 37A, 571-590.

Treisman, A. M. (1985). Preattentive processing in vision. Computer Vision, Graphics, and Image Processing, 31, 156-

177.

Treisman, A. M. (1986). Features and objects in visual processing. Scientific American, 225(5), 114-125.

Treisman, A. (1988). Features and objects: The fourteenth Bartlett memorial lecture. Quarterly Journal of Experimental Psychology, 40A, 201-237.

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

Treisman, A. M. and Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. Psychology Review, 95, 15-48.

Treisman, A., Khaneman, D. and Burkell, J. (1983). Perceptual objects and the cost of filtering. Perception and Psychophysics, 33, 527-532.

Treisman, A. M. and Patterson, R. (1984). Emergent features, attention, and object perception. Journal of Experimental Psychology: Human Perception and Performance, 10, 12-31.

Treisman, A. M. and Schmidt, H. (1982). Illusory conjunctions in the perception of objects. Cognitive Psychology, 14, 107-141.

Treisman, A. and Souther, J. (1986). Illusory words: The role of attention and top-down constraints in conjoining letters to form words. Journal of Experimental Psychology: Human Perception and Performance, 12, 3-17.

Tsal, Y. (1989). Do illusory conjunctions support the feature integration theory? A critical review of theory and findings. Journal of Experimental Psychology: Human Perception and Performance, 15, 394-400.

Ullman, S. (1984). Visual routines. Cognition, 18, 97-159.

APPENDIX A

Distribution of outliers in Experiment I and II

Experiment I

	Item type			
	Simple items		Complex items	
	Location correct	Location incorrect	Location correct	Location incorrect
Form correct	12[a] 1.0%[b]	21 1.8%	16 1.4%	21 1.8%
Form incorrect	17 1.5%	43 3.7%	16 1.4%	40 3.5%
Neutral condition	13 1.1%		11 0.9%	

[a] Raw number of outliers excluded

[b] Percentage of data points excluded in the condition

Distribution of outliers in Experiment I and II

Experiment II

	Item type			
	Simple items		Complex items	
	Location correct	Location incorrect	Location correct	Location incorrect
Form correct	24[a] 1.4%[b]	29 1.7%	19 1.1%	36 2.1%
Form incorrect	22 1.3%	61 3.5%	40 2.3%	54 3.1%

[a] Raw number of outliers excluded

[b] Percentage of data points excluded in the condition