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Selective Attention and the Organization of Visual Information

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Theories of visual attention deal with the limit on our ability to see (and later report) several things at once. These theories fall into three broad classes. *Object-based* theories propose a limit on the number of separate objects that can be perceived simultaneously. *Discrimination-based* theories propose a limit on the number of separate discriminations that can be made. *Space-based* theories propose a limit on the spatial area from which information can be taken up. To distinguish these views, the present experiments used small (< 1°), brief, foveal displays, each consisting of two overlapping objects (a box with a line struck through it). It was found that two judgments that concern the same object can be made simultaneously without loss of accuracy, whereas two judgments that concern different objects cannot. Neither the similarity nor the difficulty of required discriminations, nor the spatial distribution of information, could account for the results. The experiments support a view in which parallel, preattentive processes serve to segment the field into separate objects, followed by a process of focal attention that deals with only one object at a time. This view is also able to account for results taken to support both discrimination-based and space-based theories.

Object-Based Theories of Visual Attention

Theories of visual attention are concerned with the limit on our ability to see (and later report) several things at once. This article deals with what I call *object-based* theories (e.g., Neisser, 1967), which propose that this limit concerns the number of separate objects that can be seen. Here some predictions of this view are tested, and object-based theories are contrasted with *discrimination-based* theories (e.g., Allport, 1971, 1980) and with *spaced-based* theories (e.g., Hoffman & Nelson, 1981; Posner, Snyder, & Davidson, 1980).

The work of Neisser (1967) illustrates the object-based approach. Neisser (1967) proposed that perceptual analysis of the visual world takes place in two successive stages. The first, *preattentive,* stage segments the field into separate objects on the basis of such Gestalt properties as spatial proximity, continuity of contour, shared color or movement, and so on. The second stage, *focal attention,* analyzes a particular object in more detail. Neisser (1967) supposed that, whereas preattentive processing is parallel across objects simultaneously present in the visual field, focal attention is serial and thus is responsible for the limit on our ability to see several objects at once. Similar positions are taken by Kahneman and Henik (1981) and by Treisman, Kahneman, and Burkell (1983).

This article is concerned with some predictions following from such a theory. If subjects must report two aspects of a brief visual display, performance should depend on whether these aspects concern the same or different objects. Reporting two aspects of one object should be no more difficult than reporting only one, because focal attention is paid to the object as a whole. In contrast, reporting aspects of two different objects should be less successful, reflecting competition between these objects for focal attention.

A relevant experiment was reported by Lappin (1967). Tachistoscopic displays contained nine circles, each varying in size, color, and angle of an inscribed diameter. In one condition, a single circle was cued by a bar marker, and the subject was to report its size, color, and angle. In a second condition, three circles were cued by separate bar markers, and the subject was to report the size of one, the color of the second, and the angle of the third. Although reports were indeed more accurate in the single-object con-

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dition, the result as it stands cannot be taken as strong support for the object-based theory. First, locating and using one bar marker may be easier than locating and using three. Second, reporting aspects of three different objects required uptake of information from a wider spatial area than did reporting three aspects of one object, that is, the number of objects to be attended was confounded with the spatial distribution of information. Third, in the different-objects case, the rule describing which property to report from which object was necessarily complex, and using it to extract and to remember only the relevant information from the display must have been difficult.

A second line of evidence sometimes taken to support the object-based theory concerns effects of visual grouping. Identifying several stimuli in a complex display is improved if they are made to form a "strong" perceptual group. For example, Treisman et al. (1983) presented displays consisting of a word and an outline box. Identifying the word and the position of a break in the box's contour simultaneously was better when the box surrounded the word than when it appeared on the opposite side of fixation, even though the spatial separation between the word and critical break in the box's contour was equal in the two cases. Merikle (1980) showed that reporting the letters in one row or column of a 4 × 4 matrix is better when they are grouped by common color than when color grouping produces a conflicting organization. Similar effects of spatial grouping have been reported by Fryklund (1975) and by Kahneman and Henik (1977, 1981).

To what extent do these results support the object-based theory? Certainly the theory depends on the importance of perceptual grouping processes, because it is these that preattentively define what is treated as one object. And in the displays of Treisman et al. (1983), for example, it might be sensible to suggest that the box and the word were seen more as parts of "one object" when the box surrounded the word than when it did not. On the other hand, one may hesitate to say that a box surrounding a word or that two letters grouped by common color are attributes of one object in quite the same way as, for example, a letter's color and shape. The relation between these cases is dealt with later: For the moment, it seems best to leave open the precise relevance of grouping phenomena to the object-based theory.

It should be noted that in the context of this theory, the concept of the object serves only as an approximation to a construct whose precise details must be filled in empirically. The idea is that Gestalt grouping processes serve to package information preattentively into chunks, which then serve as units for focal attention. As a first approximation, such chunks should correspond to our intuitions concerning discrete objects; if they do not, the validity of the object-based approach will be seriously in doubt. But the precise details of preattentive information packaging must ultimately be an empirical matter. If the object-based theory is correct, then the study of visual attention and of perceptual organization must proceed together.

Other Theories

Object-based theories propose that the limit on our ability to deal simultaneously with several sources of visual information concerns the number of separate objects that can be seen. In contrast, discrimination-based theories propose a limit on the number of separate discriminations that can be made, while space-based theories propose a limit on the spatial area from which information can be picked up.

It will be shown that these three types of theories are not mutually exclusive. At the same time, evidence taken to support discrimination-based and space-based views is not entirely compelling.

Discrimination-Based Theories

One discrimination-based theory was proposed by Allport (1971). Perceptual analysis is supposed to take place in systems of analyzers, each dealing with a particular stimulus attribute such as color or form. If two discriminations involve different analyzers, they may be undertaken simultaneously without mutual interference; but when both involve the same analyzer (e.g., two form discriminations), they may not.

This proposal is not a logical alternative to an object-based theory. Limits on our ability to see several things at once may reflect both difficulties in dealing with several objects and difficulties in making several similar discriminations. Nevertheless, one may ask whether the major empirical support for the analyzer theory—provided in experiments by Allport (1971) and Wing and Allport (1972)—distinguishes the two views. Allport (1971) presented tachistoscopic displays consisting of three colored outline shapes, each containing a small black numeral. In three divided attention conditions, subjects reported colors and shapes, colors and numerals, or shapes and numerals. From the analyzer theory, Allport (1971) predicted poor performance when reporting shapes and numerals because both required form analysis. The object-based theory, in contrast, predicts poor performance when reporting either shapes and numerals or colors and numerals because both involved attention to different objects. The results were unclear. As predicted by both theories, performance when reporting colors and shapes was as good as performance in single-report control conditions (reporting only colors or only shapes). Also, as predicted by both theories, performance was poor when reporting shapes and numerals. In the crucial condition, report of colors and numerals, control levels of performance were not quite attained, though the loss was much less dramatic than for report of shapes and numerals.[1] No firm conclusion seems possible. In a second experiment Wing and Allport (1972) presented circular patches of grating made up of parallel straight lines. The grating varied in spatial frequency and in orientation, and additionally, a break gave the impression of a white band of different orientation, lying across the grating patch. As predicted by the analyzer theory, no loss from control performance occurred when subjects reported both grating frequency and grating orientation, while a substantial loss occurred when subjects reported grating orientation and break orientation. In this case, however, the object-based theory predicts exactly the same results, assuming that the display was seen as two objects (a white bar lying across the background of the grating). The condition producing differential predictions—report of grating frequency and break orientation—was not run. As things stand, evidence for the analyzer theory does not seem especially strong.

Different discrimination-based theories are possible. One proposal may be that all perceptual discriminations call for resources from some common pool, perhaps in proportion to their difficulty. If total resources are insufficient, then simultaneous discriminations interfere. This would be a natural extension of early accounts of selective attention based on information theory (Broadbent, 1958) and resembles, for example, the view of Moray (1967). Here, similarity between simultaneous discriminations might be less important than their difficulty, but again, the discrimination rather than the object would be the appropriate unit for the analysis of attention.

Space-Based Theories

Mental spotlight theories (Eriksen & Hoffman, 1973; Hoffman & Nelson, 1981; Posner et al., 1980) propose that at any given moment, attention is focused on a particular area of visual space, and only stimuli within this area receive full perceptual analysis. Sometimes it is proposed that the spotlight has a radius of about 1 ° (Eriksen & Hoffman, 1973). Or it may be suggested that as with a zoom lens, the beam can be made larger at the cost of a loss in definition (Treisman & Schmidt, 1982). But in any case, the limit on our ability to see several things at once is seen as a limit on the spatial area from which information can be picked up.

Again, space-based and object-based theories are not mutually exclusive. For example, focused attention in vision could be achieved by the combined action of two systems, one selecting a particular area of space and the other selecting a particular object

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[1] In assessing this it should be noted that even when subjects reported shapes and numerals, losses from control performance occurred only for the attribute reported second. As color was always reported second in the report of colors and numerals, a loss from control performance might have been expected only for this attribute. At each of three exposure durations, color reports were worse when reporting colors and numerals than when reporting either colors alone or colors and shapes.

within that area. One may ask, nevertheless, how clear is the evidence for the mental spotlight position. Effects of advance knowledge of spatial position, of response competition from irrelevant stimuli, and of spatial separation in divided attention will be considered in turn.

The detection or identification of a stimulus is usually facilitated by advance knowledge of its position (Bashinski & Bacharach, 1980; Eriksen & Hoffman, 1974; Posner, Nissen, & Ogden, 1978). A common interpretation is that with advance knowledge, the mental spotlight can be turned to the correct position before the stimulus is presented. However, advance knowledge of many stimulus properties other than position can have similar facilitatory effects. Detection can be improved by advance knowledge of form (Barber & Folkard, 1972; Teichner & Krebs, 1974) or of spatial frequency (Davis, Kramer, & Graham, 1983). Even when position is known in advance, identification can be further facilitated by advance knowledge of color (Humphreys, 1981a). Several factors probably contribute to such effects, including increased efficiency of selecting relevant from irrelevant information (Duncan, 1981) and reduced chance for false alarms (Davis et al., 1983). To justify the conclusion that visual attention behaves as a specifically spatial mental spotlight, one would need to show that effects of advance knowledge of position are in some way different from these more general effects. This has not been done.

Turning to response competition, Eriksen and Hoffman (1973) showed that reaction to a target letter is slowed by the presence in the visual field of irrelevant letters associated with the wrong response. Importantly, this effect rapidly diminishes as letters associated with the wrong response are moved farther away from the target. The effect occurs with various types of stimuli (Gatti & Egeth, 1978; Humphreys, 1981b; Kahneman & Henik, 1981). Depending on the stimuli used, some effect of response competition can remain with distances between the target and the irrelevant stimuli at least up to 5° (Gatti & Egeth, 1978), but a diminution in the effect with increasing distance is the rule. Again, a mental spotlight theory gives a good account of the results. The farther from the target irrelevant stimuli are placed, the less likely they are to fall within the spotlight and thus to be processed to the point at which their competing responses become strongly activated. Again, however, analogous results involving manipulation of color rather than space bring a different perspective. Humphreys (1981a) showed that effects of competing responses are diminished when the irrelevant stimulus is different in color from the target (and target color is known in advance). The general point is that when a person must distinguish relevant and irrelevant stimuli in a display, any increase in the difference between the two is likely to be helpful. When a target is to be selected on the basis of its position (e.g., adjacency to a bar marker), it is doubtless easier to tell that an irrelevant stimulus is not the target, the farther from the target position it is. Similarly, it will be easier to tell that a stimulus is not the target if it has the wrong color. Again, the conclusion that attention behaves as a specifically spatial mental spotlight could only be justified by showing that effects of spatial separation are additional to those predictable on more general grounds.

The third line of evidence concerns effects of spatial separation of stimuli that must both be identified. In an experiment by Hoffman and Nelson (1981), displays of four letters were searched to determine which of two specified targets they contained. At the same time, a small box with one side missing was presented near one of the letters, and for this stimulus, the task was to locate the missing side. The letter search task was more accurately performed when the box was adjacent to the target than when it was not, a result replicated and extended by Hoffman, Nelson, and Houck (1983). Although Hoffman and Nelson (1981) suggested that the box drew the mental spotlight to its spatial vicinity, improving the detection of adjacent targets, this account is not in line with results reported by Skelton and Eriksen (1976). Circles of eight letters were presented, with bar markers indicating a pair of letters to be judged *same* or *different*. Reaction times were shortest for adjacent and diametrically opposite pairs. It does not seem generally to be true that the identification of two stimuli is best when they are close together.

One possible interpretation of these results rests on a point raised already: Identifying several stimuli in a complex display is best when they form a strong perceptual group. It seems clear that in the displays of Hoffman and Nelson (1981), the box and the letter target would have grouped together most strongly when they were adjacent. I have confirmed that in displays like those of Skelton and Eriksen (1976), subjects rate adjacent and diametrically opposite characters as most strongly grouped. Supportive data come from an experiment by Fryklund (1975). Five letters, colored red, were to be reported from a 5 × 5 matrix; the remainder, colored black, were to be ignored. Performance was better when the five targets formed a row than when they were adjacent but arranged in no regular pattern. It seems quite likely that strength of perceptual grouping, rather than adjacency per se, determines performance in these experiments.

Thus, there are doubts over all three lines of evidence taken to support the mental spotlight theory. Overall, the evidence for this theory is not compelling.

Experiment 1

The technique of the present experiments was based on the work of Rock and Gutman (1981). These authors presented displays containing two overlapping outline shapes, one red and one green, with one shape (specified by color) to be rated for pleasingness, the other to be ignored. Each display was about 3.5° in size and was presented for 1 s. Even when tested immediately after presentation, subjects showed very poor memory for the unattended shape. Similar results were obtained by Neisser and Becklen (1975), using superimposed visual events (video scenes of games being played) each lasting 1 min.

As they stand, these results are consistent with any of the theories just discussed. An object-based theory would propose that only the target object received focal attention. A discrimination-based theory would propose that only discriminations concerning the target shape were made. Even a space-based theory might handle the results by proposing that in these rather large displays, the mental spotlight was focused only on areas of most relevance for target identification.

Consider, however, displays like those shown in the top half of Figure 1. Each consists of a box varying in size (small or large) and varying in position of a gap in its contour (right or left), with a line struck through it varying in tilt (clockwise or counterclockwise from the vertical) and varying in texture (dotted or dashed). Assuming that such a display is in fact seen as two separate objects, a box and a line (cues distinguishing the two include texture, line continuation, major axis, and perhaps instructions), it allows a direct test of the object-based theory. With a brief stimulus exposure, identifying two aspects of one object should be as easy as identifying either aspect alone, whereas identifying aspects of two different objects should be more difficult. Such results could not be explained either by a discrimination-based theory or by a space-based theory. As for the analyzer theory of Allport (1971), there is no reason to suppose that judgments concerning the same object would involve different analyzers, whereas those concerning different objects would involve the same analyzer. A discrimination-based theory based on the

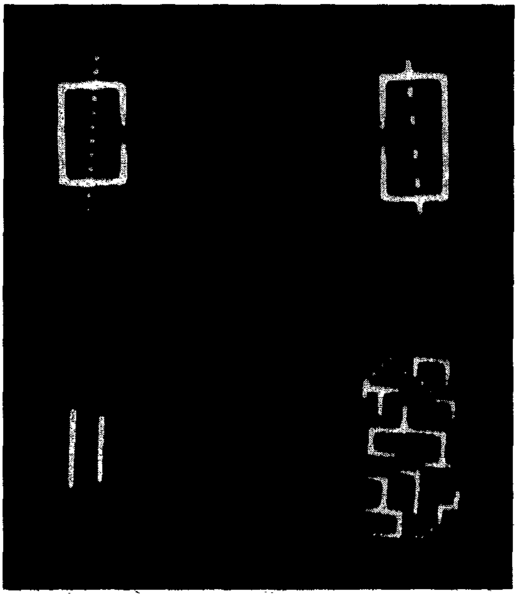

Figure 1. Displays used in Experiment 1. (Top left: Main task—small box with gap on right, dotted line with tilt clockwise. Top right: Main task—large box with gap on left, dashed line with tilt counterclockwise. Bottom left: Initial task—longer line on left. Bottom right: Mask.)

difficulty rather than on the similarity of discriminations would have no more success: Here the extent of interference between two judgments would depend only on their individual difficulties. Finally, such results could not be explained by the mental spotlight theory's proposal that simultaneous judgments are best made when the critical sources of information are close together. Notice, in particular, that the critical information for box size occurs only at the top and bottom of the display (box width is fixed), whereas the critical information for gap position occurs only in the middle of the box's sides. The spatial separation of these two is at least as great as separations for judgments concerning different objects. It seems that with this type of display, the object-based theory predicts a unique pattern of results.

Method

Subjects. Forty-eight subjects, aged between 18 and 40, were recruited from the paid subject panel of the Applied Psychology Unit. Twenty-eight were female.

Apparatus. The experiment was run on-line on a Cambridge Electronic Design laboratory computer system. Stimuli were presented on a Hewlett-Packard cathode-ray tube (CRT) display (X-Y, Model 1332A) with P24 phosphor (fast decay, bluish color). Responses were made on two pairs of keys: One pair operated with the middle and index fingers of the left hand and the other, with the corresponding fingers of the right hand. A foot switch was used to control stimulus presentation. The subject sat alone in a semidarkened room and viewed the screen from a fixed chin rest.

Procedure. Each subject served in two sessions of about an hour each, on different days. The first session was split into an initial phase to determine a suitable stimulus exposure duration for the particular subject, followed by practice on the task of the experiment proper. Data were collected only in the second session.

In the initial phase, each stimulus display was made up of two vertical lines (see Figure 1, bottom left).[2] At the viewing distance of approximately 65 cm, one line was centered 3.5′ of visual angle to the left of fixation; the other, 3.5′ of visual angle to the right. One line (at random either the left or the right) was 23′ of visual angle in length; the other, 20′ of visual angle. The task was to decide which line was longer. Responses were made with the pair of keys operated by the left hand. Within the pair, the subject pressed the key on the same side as the line judged to be longer. Responses were to be made as accurately as possible, without emphasis on speed.

Each trial began with a single fixation dot in the center of the screen. When ready, the subject pressed the foot switch to give an immediate presentation of the stimulus display. This remained for a predetermined exposure duration, then was at once replaced by a masking display. This mask, in turn, remained until the response was made, then was replaced by the fixation dot of the next trial. The mask (see Figure 1, bottom right) was an irregular pattern of horizontal, vertical, and oblique lines covering an approximately rectangular area of 52′ of visual angle vertically × 32′ of visual angle horizontally, centered on fixation.

The task was performed in blocks of 24 trials. The order of stimuli was random except that each alternative appeared 12 times per block. Exposure duration was fixed throughout a block, but changed from block to block on the following schedule. A duration of 220 ms was used for the first block. After each block, if the probability correct in that block was greater than .85, then exposure duration was decreased; if probability correct was between .65 and .85, then exposure duration was unchanged; if probability correct was less than .65, then exposure duration was increased. This procedure was continued until a criterion was reached of three blocks (not necessarily successive) at a particular exposure duration, each with a probability correct between .65 and .85.

The absolute size of decreases and increases in exposure duration was determined as follows. Consider this master sequence of exposure durations (in milliseconds): 220-180-140-100-80-60-40. Starting at 220, subjects worked down this sequence either until criterion was reached or until one block had a probability correct of less than .65. In the latter case, the size of the steps in the master sequence was then halved, and thereafter increases and decreases in exposure duration took place in these half steps until criterion was reached.

Thus, each subject ended the initial phase having established a criterion exposure duration that ranged from 50 ms to 100 ms, with a mean of 79.2 ms. Pilot work suggested that this criterion exposure duration, when used for data collection in the experiment proper, would give a suitable overall level of performance.

In the experimental task, each stimulus display was made up of a rectangular outline box with an oblique line struck through it (see Figure 1, top left and right). Both the box and the line were centered on fixation. Both varied in two dimensions.

The box, 20′ of visual angle in width, was either 30′ or 37′ of visual angle in height. It had a gap of 2.5′ of visual angle in the center of either its left or its right side.

The line, 46′ of visual angle in length, was tilted 4°1′ either counterclockwise or clockwise from the vertical. In texture it was either dotted or dashed. In either case, the line was made up of a total of 12 illuminated dots. In the dotted case, these dots were spaced evenly along the line's length. In the dashed case, they were grouped into 6 clearly separate dashes. Both textures appeared quite different from the texture of the box. The box too, of course, was made up of illuminated dots, but adjacent dots in its outline were sufficiently close (separation was 0.45 times that of the dotted line) to give the impression of a continuous line more than that of a line of separate dots.

Though stimulus displays potentially varied along four dimensions termed *box(size), box(gap), line(tilt),*

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[2] Detailed display descriptions are available from the author.

and *line(texture)*, for any given subject only two dimensions were relevant, and only these two varied. When not varying, box(size) was fixed at 30′ of visual angle, box(gap) was fixed on the right, line(tilt) was fixed counterclockwise, and line(texture) was fixed at dashed.

Trials resembled those of the initial phase. When fixated, the subject pressed the foot switch to initiate the stimulus display. Following a predetermined exposure duration, the mask (see Figure 1, bottom right) appeared and remained until the response was complete. Subjects were asked to respond as accurately as possible, without emphasis on speed.

Responses were made as follows. One of a subject's two relevant dimensions (termed the *first-reported* dimension) was assigned to the pair of keys operated by the left hand, the other (the *second-reported* dimension), to the pair operated by the right. For any 1 subject, this assignment was fixed throughout the experiment. In some blocks (*single-judgment* blocks), subjects made a judgment about only one dimension and correspondingly responded only with one hand. In other blocks (*double-judgment* blocks), judgments were made for both dimensions. In these blocks order of report was fixed, and the left-hand response was always made first. Within each pair of keys, let the left key be termed Key 1 and the right key be termed Key 2. For judgments concerning box(size), a response on Key 1 indicated a judgment of small, and a response on Key 2, a judgment of large. For box(gap), Key 1 indicated left, and Key 2 indicated right. For line(tilt), Key 1 indicated counterclockwise, and Key 2 indicated clockwise. For line(texture), Key 1 indicated dotted, and Key 2 indicated dashed.

When the initial phase of determining an appropriate exposure duration was complete, the remainder of the subject's first session was devoted to practice in the experimental task. Practice was given under three conditions: single-judgment conditions for each of the subject's two relevant dimensions and the double-judgment condition. Performance was blocked by condition, and the order of conditions was counterbalanced across subjects (orthogonally to other factors). Within each condition, there were six blocks of 24 trials, with the order of stimuli random in each block. The first block was run at an exposure duration three steps up in the master sequence from the subject's criterion duration (the +3 duration); the second, at the +2 duration; the third, at the +1 duration; and the remaining three, at the criterion duration. If the criterion duration was at a half step in the master sequence (e.g., 90 ms), the +1 duration was taken to be the first step above (100 ms). This schedule of practice was designed to teach each discrimination initially under conditions of relatively good visibility. The percentage correct was shown to the subject at the end of each block.

In the second session, the subject again performed in three conditions, in the same order as before. Within each condition, two practice blocks of 24 trials each, the first at the +3 duration and the second at the criterion duration, were followed by six experimental blocks of 48 trials each, all at the criterion duration. Only data from the experimental blocks were used in later analyses. Within each 48-trial block, each of the four stimulus alternatives (defined by the two possible values of the subject's two varying dimensions) occurred 12 times. Otherwise, stimulus sequences were random. Again, the percentage correct was shown at the end of each block.

Table 1
Experiment 1: Proportion Correct in Each Condition

Group	First-reported dimension		Second-reported dimension	
	Single	Double	Single	Double
Same-object	.844	.834	.849	.834
Different-objects	.786	.788	.796	.715

Note. Single = single-judgment. Double = double-judgment.

In single-judgment conditions, the importance of attending only to the one dimension to be judged was emphasized, while in double-judgment conditions, it was stated that the two dimensions were equally important, though one was always to be reported first. Repeated emphasis was given to the importance of careful fixation before stimulus initiation and to the avoidance of keyboard errors.

Design. Subjects were divided equally into two groups. In the different-objects group, the subject's two relevant dimensions concerned different objects, that is, one concerned the box and the other, the line. In the same-object group, the subject's two relevant dimensions concerned the same object.

Each group was divided equally into subgroups on the basis of the particular dimensions assigned to be relevant. The different-objects group was divided into eight subgroups of 3 subjects each, corresponding to the four possible pairs of dimensions from different objects [box(size) plus line(tilt), box(size) plus line(texture), box(gap) plus line(tilt), box(gap) plus line(texture)] multiplied by the two possible orders of report (i.e., assignment of dimensions to hands) within each pair. The same-object group was divided into four sub-groups of 6 subjects each, corresponding to the two possible pairs of dimensions from the same object [box(size) plus box(gap), line(tilt) plus line(texture)] multiplied by the two possible orders of report. Note that each display dimension appeared 6 times in each of the four cells (first- vs. second-reported dimension, different-objects group vs. same-object group) of the design.

Verbal descriptions of displays. After the experiment was complete, 10 new subjects were each asked to give a spontaneous verbal description of an experimental display. In all 10 cases, the display was said to show a box with a line through it. This reinforces the assumption that these displays were seen to contain two separate objects.

Results and Discussion

The major results are shown in Table 1, which gives the mean proportion correct in each condition. For the same-object group, performance was very similar in the single-judgment and double-judgment conditions. For the different-objects group, a decline in performance occurred in the double-judgment condition, though it was confined entirely to the second-reported dimension.

The data were examined by analysis of variance (ANOVA), with group (same-object vs. different-object) as a between-subjects factor, and with dimension (first-reported vs. second-reported) and condition (single-judgment vs. double-judgment) as within-subjects factors. There were significant main effects of group, $F(1, 46) = 5.2, p < .05$, and of condition, $F(1, 46) = 7.0$, $p < .02$; and significant interactions of Dimension × Condition, $F(1, 46) = 6.7$, $p < .02$, and of Group × Dimension × Condition, $F(1, 46) = 5.1, p < .05$. This last interaction is the important one and shows that effects of condition were confined to the second-reported dimension of the different-objects group.

These conclusions were confirmed by supplementary analyses that treated each group separately. For the same-object group, there was no significant effect of dimension, condition, or their interaction (all Fs < 1). For the different-objects group, there were significant effects of condition, $F(1, 23) = 8.8, p < .01$, and of Dimension × Condition, $F(1, 23) = 8.7, p < .01$.

As a whole, these data confirm the predictions of the object-based theory. If two judgments concern the same object, they do not interfere; but if they concern two different objects, these may compete for focal attention. The data suggest that the object whose property is to be reported first is favored, and performance on the other is allowed to decline.

Further breakdowns of the data, however, revealed two troublesome details. The first concerned the different-objects group. Although in this group as a whole there was an advantage for single- over double-judgments, this trend vanished for those subjects whose second-reported dimension was line(texture). For these 6 subjects, the mean single-judgment advantage (in terms of proportion correct) was $-.020$ for the first-reported dimension and was .000 for the second-reported dimension. Although this result could well have been due to noise in the data, it does suggest a possible interpretation in terms of a variant of Allport's (1971) analyzer theory. Whereas the dimensions box(size), box(gap), and line(tilt) all concern the broad question of *where* lines are in the visual field, line(texture) concerns the *quality* of a line. It may be suggested that judgments concerning different objects interfere only when they involve the broad question of where lines are. Data for those 6 subjects having line(texture) as their *first*-reported dimension contradict this proposal. Mean single-judgment advantages were .017 and .102 for first- and second-reported judgments, respectively. Nevertheless, the proposal seemed worth a further test. Experiment 2 was run to check on the results obtained for line(texture) and to see whether they would generalize to another dimension concerning line quality—brightness.

The second troublesome detail of the results concerned the same-object group. The data were quite clear for those subjects whose judgments concerned the line. Averaging over first- and second-reported dimensions, the mean advantage of single-judgments over double-judgments was $-.008$, with a standard error of .011. Though the conclusion that performance was equal in the two conditions rests on a failure to reject the null hypothesis, any "true" advantage for single-judgments can at most have been very small. Data were less clear, however, for those subjects whose judgments concerned the box. The mean advantage of single-judgments was .034, with a standard error of .026. These more noisy data do not allow a strong conclusion that performance was effectively equal in single- and double-judgment conditions. In fact, there was a hint that results depended on order of report. It was the subgroup for whom box(size) was first-reported and box(gap) was second-reported who showed evidence of better performance in single-judgments (a mean advantage over double-judgments of .063). This trend held only for 4 of the 6 subjects in this subgroup, but should be remembered for comparison with later results.

It is crucial to know whether judgments of box(size) and box(gap) can be made together without mutual interference. Line(tilt) and line(texture) are both represented in precisely the same place—along the whole length of the line—whereas box(size) and box(gap) are not. If only the former pair of judgments can be made without interference, the conclusion may be, in line with the mental spotlight theory, that interference occurs whenever the information for two judgments is spatially separate, not when the two concern different objects. Box judgments were examined further in Experiments 3 and 4.

Experiment 2

Part 1

In Part 1 of Experiment 2, each display again consisted of a box with a line struck through it. Again, only two dimensions were relevant for a single subject, this time always concerning different objects. For half of the subjects, one dimension concerned tilt and the other concerned texture. Counterbalancing was used to determine whether the line varied in tilt and the box varied in texture or vice versa. For the remaining subjects the dimensions of tilt and brightness were similarly manipulated. Order of report was now a crucial variable, because the results of Experiment 1 suggested that performance losses in the double-judgment condition might occur only if tilt was the second-reported dimension.

Part 2 of Experiment 2 was a control experiment in which tilt and brightness varied for the same object, either the box or the line.

The data for individual subjects in Experiment 1 suggested that little had been gained by establishing a separate exposure duration for each. In Experiment 2 the same exposure duration was used for all subjects.

Method

Subjects. Twenty-four subjects, aged between 23 and 41, were recruited as before. Nineteen were female.

Procedure. Each stimulus display was made up of a rectangular outline box (33′ of visual angle vertically × 18′ of visual angle horizontally) with a line (46′ of visual angle in length) struck through it. For half of the subjects (texture group), one object varied only in texture (dotted or dashed), whereas the other varied only in tilt (counterclockwise or clockwise from the vertical). For the remaining subjects (brightness group), one object varied only in brightness (dim or bright), whereas the other varied only in tilt (counterclockwise or clockwise). Again, only two dimensions of the display varied for a given subject.

In the texture group, the object varying in texture was always vertical. The dotted and dashed textures themselves were made up in the same way as in Experiment 1. The other object, varying in tilt, was always drawn with the dotted texture. As in Experiment 1, the tilt was 4° 1′ counterclockwise or clockwise from the vertical.

In the brightness group, the object varying in brightness was always vertical. Brightness was manipulated by varying the spacing between adjacent dots in a line. Although absolute brightnesses were not measured (and due to limitations of the display device were not precisely replicable across sessions), the ratio of spacings in dim and bright lines was 1.55; or in other words, for a given line length, a bright line contained 1.55 times as many dots as a dim one. In both cases, spacings were sufficiently short to give the appearance of a continuous line more than that of lines of separate dots, and the difference between the two cases did accordingly appear to be one of brightness rather than one of spacing. The other object, varying in tilt, was always drawn with the dotted texture of Experiment 1 (spacing was twice that of the dim lines). Tilt, again, was 4° 1′ clockwise or counterclockwise from the vertical.

Responses were made in the same way as in Experiment 1. Within a pair of keys, response assignments for texture and tilt judgments were as before, while for brightness, Key 1 indicated a judgment of dim, and Key 2 indicated a judgment of bright.

Events and timing on each trial were similar to those of Experiment 1, with one exception. During Experiment 1, some subjects had complained of feeling "dazed," "hypnotized," and so on. Pilot work suggested these sensations could be minimized by forcing short pauses between trials, giving the subject an opportunity to blink if desired. Accordingly, mask offset on each trial was followed by a blank interval of 1 s before the onset of the fixation point for the next trial. Subjects were encouraged to blink between trials if they were having trouble "focusing or concentrating."

Each subject served in two sessions of about an hour each, on different days. In each session, the subject performed under three conditions: single-judgment conditions for each of the two relevant dimensions and the double-judgment condition. Performance was blocked by condition; the order of conditions, counterbalanced across subjects (orthogonally to other factors), was the same for a given subject across sessions.

In the first session, there were seven blocks of 24 trials per condition, and exposure durations (in milliseconds) were 220, 180, 140, 100, 80, 80, and 80, respectively. In the second session, performance in each condition consisted of two practice blocks of 12 trials each, with exposure durations of 180 ms and 80 ms, respectively, followed by four experimental blocks of 48 trials each, with an exposure duration of 80 ms. Stimulus sequences were constructed as in Experiment 1, and again the percentage correct was shown at the end of each block. Again, only data from the 48-trial blocks of the second session were analyzed.

Design. The 12 subjects in the texture group were divided into two equal subgroups. For 6 subjects, tilt was the first-reported dimension and texture was the second-reported dimension, an arrangement reversed for the other 6 subjects. Each subgroup was further subdivided into two sets of 3 subjects each, according to whether the box varied in tilt and the line varied in texture or vice versa. The 12 subjects in the brightness group were subdivided similarly.

Part 2

The results of Experiment 1 showed that when judgments of tilt and texture concern the same object, performance is equal in single-judgment and double-judgment conditions. Part 2 of Experiment 2 was run to check that the same applies to judgments of tilt and brightness.

Part 2 was similar to Part 1 (brightness group) except that for a given subject, tilt and brightness both varied for the same object, either the box or the line. The object not varying was always vertical and was drawn with dotted texture. Note that in Part 1 of Experiment 2, the object that varied in tilt was always drawn with a dotted texture, which made tilt harder to determine than in Part 2 because there were relatively few dots per unit line length. To compensate for this, in Part 2 the exposure duration was reduced. The sequence (in milliseconds) used for each condition in the first session was 180-140-100-80-60-60-60, whereas durations of 140 ms (first practice block) and 60 ms (remaining blocks) were used for each condition in the second session.

Twelve subjects, aged between 18 and 41, were recruited as before. Six were female.

Results and Discussion

Experiment 2: Part 1

The proportion correct in each condition of Part 1 is shown in Table 2. Because preliminary analyses showed that results were the same whether the line varied in tilt and the box varied in quality (texture or brightness) or vice versa, this factor is not considered further. Data are shown separately for the texture and the brightness groups and for the two orders of report. For all groups performance was better in single-judgment conditions than in double-judgment conditions. For all groups except that reporting tilt first and texture second, the single-judgment advantage was greater for the second-reported dimension.

Table 2
Experiment 2, Part 1: Proportion Correct in Each Condition

	First-reported dimension		Second-reported dimension	
Group	Single	Double	Single	Double
Texture				
Tilt first	.910	.844	.959	.937
Tilt second	.883	.834	.884	.794
Brightness				
Tilt first	.744	.722	.872	.792
Tilt second	.871	.837	.812	.673

Note. Single = single-judgment. Double = double-judgment.

The data were examined by an ANOVA with group (texture vs. brightness) and order (tilt first vs. tilt second) as between-subjects factors and with dimension (first-reported vs. second-reported) and condition (single-judgment vs. double-judgment) as within-subjects factors. The effect of condition was significant, $F(1, 20) = 29.1$, $p < .001$, indicating the overall superiority of single-judgments. The Dimension × Condition interaction was marginal, $F(1, 20) = 3.8$, $p < .07$, as was the Group × Dimension × Condition interaction, $F(1, 20) = 4.1$, $p < .06$, hinting at a stronger Dimension × Condition interaction for the brightness group. Neither the Order × Dimension × Condition interaction, $F(1, 20) = 2.7$, nor the Group × Order × Dimension × Condition interaction, $F(1, 20) = 0.2$, was significant. Other significant effects were group, $F(1, 20) = 10.9$, $p < .01$, showing the overall superiority of the texture group, and the Order × Dimension interaction, $F(1, 20) = 5.8$, $p < .05$, showing that tilt judgments tended to be less accurate than judgments of either texture or brightness.

In a supplementary analysis, the data for the group having tilt as their first-reported dimension and texture as their second-reported dimension were considered alone. Even for this group the effect of condition was significant, $F(1, 5) = 8.4$, $p < .05$.

Experiment 2: Part 2

The proportion correct in each condition of Part 2 is shown in Table 3. The data confirm that when two judgments concern the same object, performance is equal in single-judgment and double-judgment conditions.

Table 3
Experiment 2, Part 2: Proportion Correct in Each Condition

	First-reported dimension		Second-reported dimension	
Group	Single	Double	Single	Double
Tilt first	.928	.920	.750	.774
Tilt second	.824	.817	.939	.933

Note. Single = single-judgment. Double = double-judgment.

The data were examined by an ANOVA, with order as a between-subjects factor and dimension and condition as within-subjects factors. The only significant effect was the Order × Dimension interaction, $F(1, 10) = 53.8$, $p < .001$, showing that tilt was judged more accurately than brightness.

In terms of proportion correct, the mean advantage of single-judgment over double-judgment conditions was −.001, with a standard error of .014. Again, though the conclusion that performance was equal in the two conditions reflects a failure to reject the null hypothesis, we may be confident that any true advantage for the single-judgment case can at most have been small.

A further ANOVA compared these results with those obtained for the brightness group in Part 1 of Experiment 2. Between-subjects factors were experiment (Part 1 vs. Part 2) and order, and within-subjects factors were dimension and condition. The main effect of condition was significant, $F(1, 20) = 8.8$, $p < .01$, and there were significant interactions of Experiment × Condition, $F(1, 20) = 9.1$, $p < .01$, and of Experiment × Dimension × Condition, $F(1, 20) = 7.5$, $p < .02$, showing that the effect of condition was confined to Part 1, and in Part 1 occurred especially for the second-reported dimension. The remaining significant effects were experiment, $F(1, 20) = 5.4$, $p < .05$, reflecting better performance overall in Part 2, and the Experiment × Order × Dimension interaction, $F(1, 20) = 24.0$, $p < .001$, showing that tilt was judged less accurately than brightness in Part 1, but more accurately in Part 2. The reason for this—that the tilted object was drawn with a dotted texture in Part 1—has already been described.

Taken together, the results of Parts 1 and 2 of Experiment 2 provide further support for the object-based theory. In particular they disconfirm the idea that simultaneous judgments concerning different objects may interfere only when both concern the broad question of where lines are. There seems no variant of Allport's (1971) analyzer theory that could account for the results. Simultaneous judgments of tilt and brightness interfere when they concern different objects, but not when they concern the same object. Though the result is weaker, the same probably holds for judgments of tilt and texture.

In all likelihood, there is something unusual about texture judgments. A further group of 6 subjects run under the conditions of Experiment 2, Part 1 with tilt as the first-reported dimension and texture as the second-reported dimension, gave proportions correct of .874 and .887, respectively, for first- and second-reported dimensions in single-judgment conditions, compared with .871 and .866, respectively, for double judgments. These data suggest again that the single-judgment advantage is reduced when the second-reported dimension is texture. Nevertheless, Experiment 2, Part 1 showed that even then this advantage can remain significant. Although further research on texture judgments may be interesting, the general principle stands that performance suffers when a person must make simultaneous judgments concerning different objects.

Experiment 3

In Experiment 1 it was not fully clear that judgments of box(size) and box(gap) can be made together without mutual interference. The issue is especially important because these judgments, though concerning the same object, rest on information at separate spatial locations. Experiment 3 reexamined performance on these judgments, using the improved technique (forced pause of 1 s between trials) of Experiment 2. This time the box was displayed alone, and for all subjects, size and gap were the relevant dimensions.

Method

Subjects. Twenty-four subjects, aged between 18 and 42, were recruited as before. Fifteen were female.

Design and procedure. Each stimulus display consisted of a box varying in size and side of gap, exactly as in Experiment 1. There was no line struck through. For half of the subjects, size was the first-reported dimension and gap was the second-reported dimension, an arrangement reversed for the other half.

The procedure was copied exactly from Experiment 2, as were the events and the timing of a single trial. In an attempt to maximize sensitivity, two different exposure durations were used. For half of the subjects, a duration of 70 ms was substituted wherever 80 ms had been used in Experiment 2, including the experimental blocks of the second session from which data were analyzed. For the remaining subjects, the duration of 80 ms was retained. This factor was varied orthogonally to the others; otherwise, counterbalancing was as before.

Results

The mean proportion correct in each condition is presented in Table 4. Data are shown separately for each order of report and exposure duration. In terms of proportion correct, the mean advantage of single-judgments over double-judgments was .014, but again, as in Experiment 1, this advantage seemed to be confined to those subjects reporting size first and gap second.

The data were examined by an ANOVA, with order (gap first vs. gap second) and exposure duration (70 ms vs. 80 ms) as between-subjects factors and dimension (first-reported vs. second-reported) and condition (single-judgment vs. double-judgment) as within-subjects factors. Neither the effect of condition, $F(1, 20) = 2.8$, nor the Order × Condition interaction, $F(1, 20) = 2.9$, was significant. The only significant effect was the Order × Dimension interaction, $F(1, 20) = 15.7$, $p < .001$, indicating that gap was more accurately judged than size.

For the 12 subjects reporting gap first, the mean advantage of single-judgments over double-judgments was .000, with a standard error of .008. Again, any true single-judgment advantage can at most have been very small.

For the 12 subjects reporting gap second, the mean advantage of single-judgments over double-judgments was .027, with a standard error of .013. Ten subjects showed better performance in the single-judgment condition. Again it seems unwise, taking these data in conjunction with those of Experiment 1, to conclude that with this order of report, simultaneous judgments of size and gap can be made without mutual interference.

Table 4
Experiment 3: Proportion Correct in Each Condition

	First-reported dimension		Second-reported dimension	
Group	Single	Double	Single	Double
Gap first				
70 ms	.913	.916	.754	.766
80 ms	.931	.920	.845	.842
Gap second				
70 ms	.872	.852	.917	.884
80 ms	.886	.839	.941	.932

Note. Single = single-judgment. Double = double-judgment.

Experiment 4

What special difficulty could arise when a judgment of size must be reported before a judgment of gap? Experience in the task suggested a possible effect of response compatibility.

When both properties of the box are attended, subjectively one "sees" the size and the side of the gap and then must choose a response. Because the side of the gap is itself coded in terms of left and right, there is a particularly compelling mapping onto the choice between left and right keys to be made within the pair operated by each hand. Reporting size before gap, I became aware that it was persistently distracting to be unable to make this compelling response first, on the left pair of keys.

The importance of this may be tested simply by turning the display on its side. Now, neither gap nor size would have an especially compelling mapping onto response key and in this respect would resemble all other judgments used in the present work. Accordingly, the advantage of single-judgments over double-judgments should vanish.

Method

Subjects. Twelve subjects, aged between 19 and 38, were recruited as before. Six were female.

Design and procedure. Experiment 4 was similar to Experiment 3 in all respects except that (a) size was always the first-reported dimension, and gap was the second-reported; (b) the display device was turned on its side (counter-clockwise) so that the box varied in width rather than height, and the gap was in the top or bottom. Within the right-hand pair of keys, Key 1 indicated a judgment of top, and Key 2, a judgment of bottom. Exposure duration was varied as in Experiment 3, taking values of either 70 ms or 80 ms in the experimental blocks of the second session.

Results and Discussion

The mean proportion correct in each condition is shown in Table 5. There was no advantage for single-judgments over double-judgments.

The data were examined by an ANOVA, with exposure duration (70 ms vs. 80 ms) as a between-subjects factor and with dimension (first-reported vs. second-reported) and condition (single-judgment vs. double-judgment) as within-subjects factors. The effect of condition was not significant, $F(1, 10) = 3.4$, and in any case was in the direction of an advantage for double-judgments. The only significant effect was dimension, $F(1, 10) = 9.6$, $p < .02$, showing that gap was judged more accurately than size.

In terms of proportion correct, the mean advantage of single-judgments over double-judgments was −.017, with a standard error of .009. Again, it is safe to conclude that any true advantage for single-judgments can at most have been very small.

A further ANOVA compared these data with those obtained when size was reported first in Experiment 3. Factors were as before, with the addition of experiment (3 vs. 4) varying between subjects. The Experiment × Condition interaction was significant, $F(1, 20) = 7.1$, $p < .02$, confirming that turning the display on its side reduced the advantage of the single-judgment condition. The only other significant effect was dimension, $F(1, 20) = 7.7$, $p < .02$, again showing that gap was judged more accurately than was size.

In all probability, the results of Experiments 1 and 3—suggesting a special difficulty in reporting box(size) and box(gap) in that order—were due to a compatibility effect. When this effect is avoided, judgments of the two attributes can be made together without mutual interference.

In these experiments, an important general question concerns the possibility of information loss during output. When two responses are to be made, does it happen that the second answer is forgotten while the first is given or that confusion over key assignments causes mistakes to be made? The results of same-object groups suggest that the answer usually is no: If compatibility effects are avoided, two key-press responses can be made in turn without loss of accuracy. It should be remembered that accuracy was stressed in the experimental instructions, and subjects were encouraged to take as much time as they needed to make their responses. It seems likely that this procedure was successful in producing performance dependent only on the events of stimulus input, not on response output.

Table 5
Experiment 4: Proportion Correct in Each Condition

Exposure duration	First-reported dimension		Second-reported dimension	
	Single	Double	Single	Double
70 ms	.840	.847	.874	.885
80 ms	.885	.912	.931	.955

Note. Single = single-judgment. Double = double-judgment.

General Discussion

The present results confirm the predictions of the object-based theory. Two judgments concerning the same object can be made together without mutual interference, whereas two judgments concerning different objects cannot. The results cannot be explained on the basis of either the similarity of discriminations (Experiment 2) or the spatial distribution of information (Experiments 3 and 4).

A rider should be added to the conclusion on judgments concerning the same object. Although the present results agree with those of Allport (1971) and Wing and Allport (1972), different findings were described by Egeth and Pachella (1969). The stimulus was a dot varying in horizontal and vertical positions within a square, with 15 alternative positions along each dimension. With stimulus exposures up to 2 s, judgments on each dimension suffered when the two were required simultaneously. When the number of response alternatives is large (the absolute judgment task), the crucial problem would seem to be to map one's perceptual impression onto the response categories. In the experiment of Egeth and Pachella (1969), for example, this would require something like 14 separate (stored) response criteria for each dimension and a mapping of perceptual input onto these criteria. It may be impossible to carry out such a complex, rather deliberative mapping for two dimensions simultaneously even though they may concern the same object. This problem deserves further study.

It should be clear that at present we have no more than the skeleton of an object-based theory. The present data confirm that focal attention acts on packages of information defined preattentively and that these packages seem to correspond, at least to a first approximation, to our intuitions concerning discrete objects. As discussed before, however, the exact details of preattentive packaging must be filled in empirically. The present results suggest that an object-based theory is along the right lines; but it will take much further work to refine our knowledge of preattentive perceptual organization beyond this first crude idea of the "discrete object."

Earlier, evidence was reviewed to show that the simultaneous identification of several stimuli is best when they form a strong perceptual group. It was noted that this evidence is sometimes taken to support the object-based theory, which does depend on the importance of preattentive grouping. How does such evidence fit with the present findings?

First, there is now empirical justification for our earlier hesitation to refer to two letters grouped by spatial arrangement or color as parts of "one object," in quite the same sense as, for example, a box's tilt and its brightness. Although it is true that letters grouped strongly together are identified better than those grouped less strongly, it is not true that they can be identified without any mutual interference. Adding extra letters to a group, for example, causes performance to decline (Kahneman & Henik, 1977).

With this in mind, there seem to be two possible approaches to the integration of present and previous results. The first would interpret grouping strength as a simple continuum. To explain why there is no interference at all in the simultaneous identification of, for example, a box's tilt and its brightness, it would simply be proposed that the grouping together of these two features is even stronger than the grouping of separate letters by spatial arrangement or common color. This approach would interpret the present data as simply an extreme case of strong grouping effects.

The second approach is based on the hierarchical organization of visual information. Although less parsimonious than the first, it has the advantage of capturing the intuition of a qualitative difference between the case of two letters grouped together, which remain two objects, and the case of a box's tilt and its brightness, which are two aspects of a single object. Consider the following problem for the object-based theory. Although the claim is that focal attention deals with whole objects, common sense strongly suggests that attention to a whole skyscraper would be inappropriate for determining whether there is a crack in the third window from the left on the 13th floor. What we need is an idea of the sorts of information likely to be coded in the "chunks" corresponding to "objects" at different levels of a hierarachy: building, window, and so forth. It seems highly likely that properties such as its height, shape, and texture would be coded in the representation of a whole building, whereas a crack in one of its windows would not. Although such ideas obviously should be checked by experiment, they suggest the following approach to effects of grouping. In a mixed display, for example, of red and blue letters, there are objects present at (at least) two levels. At the higher level would be the shape formed by the whole set of red letters. At the lower level would be the shapes of individual letters. Focal attention at the higher level might be sufficient to determine the shape formed by the whole set of red letters; but at this level, the identities of individual letters would not be coded. To identify and to report individual letters, it might be necessary to direct focal attention to each in turn. To account for grouping effects like those of Kahneman and Henik (1977) and Merikle (1980), one would propose that directing focal attention to several objects in turn is easier when these form part of a single object at a higher level. (This might be analogous to paying attention first to a whole object and then "zooming in" for closer examination of a particular part.) However, a separate act of focal attention is still needed for each, producing mutual interference between them. To account for effects like those obtained in the present experiments, one would propose that when focal attention is paid to an object, all features coded as properties of the whole (size, shape, color, etc.) are perceived without mutual interference. This approach to integrating the present findings with work on perceptual grouping seems well worth further work.

As discussed previously, object-based, discrimination-based, and space-based theories are not mutually exclusive. It is possible that there are several separate contributions to the limit on our ability to deal with several sources of visual information at once. Thus, although it is clear in retrospect that the results of Allport (1971) and Wing and Allport (1972) do not lend unambiguous support to the analyzer theory, such support may well arise in an experiment that orthogonally manipulates the similarity between discriminations and their reference to the same or to different objects. Similarly, although doubts have been raised over the evidence currently taken to support a mental spotlight theory, experiments should be done that vary the spatial separation of information for discriminations concerning both the same and different objects.

Two variations of the mental spotlight theory are worth particular consideration. First, it may be suggested that this spotlight is oriented not in two-dimensional space but in three-dimensional space. If this were the case and if the present displays were interpreted as depicting two objects separated in depth, then the results might be explained without reference to an object-based theory. Judgments concerning the same object would rest on information at the same (perceived) location in depth, whereas those concerning different objects would not.[3] The difficulty with this account is that subjectively the displays appeared quite flat. Of 10 subjects asked to give verbal descriptions of these displays (see Experiment 1), none mentioned spontaneously a separation in depth between the box and the line, and when specifically asked, all preferred to describe displays as flat rather than as containing separation in depth. In the semidarkened room, there were ample cues to the true depth of the screen and the display. Any illusory separation of objects in depth would have had to have overridden veridical information. For this reason, an account of the results in terms of a three-dimensional mental spotlight seems quite unlikely, though not completely impossible.

In a different elaboration of the space-based view, Treisman (Treisman, 1982; Treisman & Gelade, 1980; Treisman & Schmidt, 1982; Treisman et al., 1983) suggested that visual attention acts to take up all information from a particular area of space but that the shape of this area can be determined by a prior stage of Gestalt grouping and segmentation of the visual field, very much as envisioned by the object-based theory. For example, it may well be possible for such a mental spotlight to assume the shape of either the box's contour or the line, in the present displays; and indeed this may be expected if grouping cues indicate that the box and the line are separate objects. At first sight, it seems that this is better viewed as an object-based theory rather than a space-based theory. The chunk of information dealt with by focal attention is determined by Gestalt grouping, not by anything specifically spatial. A further point is missed by such a conclusion, however. Treisman proposed that the function of focal attention is to link together information concerning an object's different attributes. Preattentively, separate "maps" of the visual field are formed for different stimulus attributes: color, size, aspects of shape, and so forth. Within each map, Gestalt grouping factors can operate to indicate candidate areas for focal attention. Focal attention then acts on a particular candidate area and links together into a single perceived object the information from this area in all the separate maps. Now, although it is true that the chunk of information dealt with by focal attention is determined by Gestalt grouping (cf. an object-based theory), it is also true that an object's different features are

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[3] I am grateful (?) to Mike Posner for pointing this out.

conjoined specifically by virtue of shared location. This has testable consequences: For example, it should only be possible to know which color goes with which shape in a display if it is also known in which location both occur (Treisman & Gelade, 1980). It is quite possible that the object-based theory is correct with regard to the chunk of information dealt with by focal attention, but that in the process of focal attention, an object's different attributes are conjoined by virtue of shared location.

It may be noted, however, that another claim of Treisman's theory is somewhat inconsistent with the present results. Treisman suggested that focal attention can be bypassed if it is not important to know how attributes in a display are conjoined: Information concerning several objects can be obtained in parallel. Suppose, for example, that one is presented with a green T and a red O. Focal attention is not required to tell that the display contains green, red, a T, and an O. It is only required to distinguish a green T and a red O from a green O and a red T. Similarly, Treisman suggested that focal attention can be bypassed if prior knowledge is sufficient to determine correct conjunctions. Now consider, as an example, a subject judging box(tilt) and line(brightness) in the present Experiment 2. Strictly speaking, conjunction information was unnecessary. To perform correctly, the subject needed only to know, for example, that somewhere in the display there was a contour tilted slightly clockwise and that somewhere there was a contour that was bright. Furthermore, prior knowledge was sufficient to tell that only the box could be tilted, and that only the line could be dim or bright. Similar arguments apply to other cases in which subjects made simultaneous judgments concerning different objects in the present experiments. The data suggest that focal attention is not optional in the process of reporting judgments concerning visual stimuli. Even when conjunction information was both unnecessary and predictable, subjects either could not or did not deal with different objects in parallel.

In conclusion, the present results show that the limit on our ability to deal simultaneously with several sources of visual information is at least in part a limit on the number of separate objects that can be seen. It is for future work to show whether this in fact is the only limit responsible for the phenomena of visual attention.

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Domjan Appointed Editor, 1986–1991

The Publications and Communications Board of the American Psychological Association announces the appointment of Michael Domjan, University of Texas at Austin, as editor of the *Journal of Experimental Psychology: Animal Behavior Processes* for a 6-year term beginning in 1986. As of January 1, 1985, manuscripts should be directed to:

Michael Domjan, Editor
Department of Psychology
University of Texas
Austin, Texas 78712

Manuscript submission patterns for *JEP: Animal* make the precise date of completion of the 1985 volume uncertain. The current editor, Donald Blough, will receive and consider manuscripts until December 31, 1984. Should the 1985 volume be completed before that date, manuscripts will be redirected to Domjan for consideration in the 1986 volume.