Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Visual Attention

Jeremy M Wolfe
Center for Ophthalmic Research
Brigham and Women's Hospital and Harvard Medical School
Boston, MA 02115

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

1. Introduction

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

> What a piece of work is man, how noble in reason, how infinite in faculties....
>
> (Hamlet, 2:2:312-313)

Hamlet was wrong. We are dramatically limited in our faculties. Look at the center of Figure One and find a big black circle surrounding a small white square.

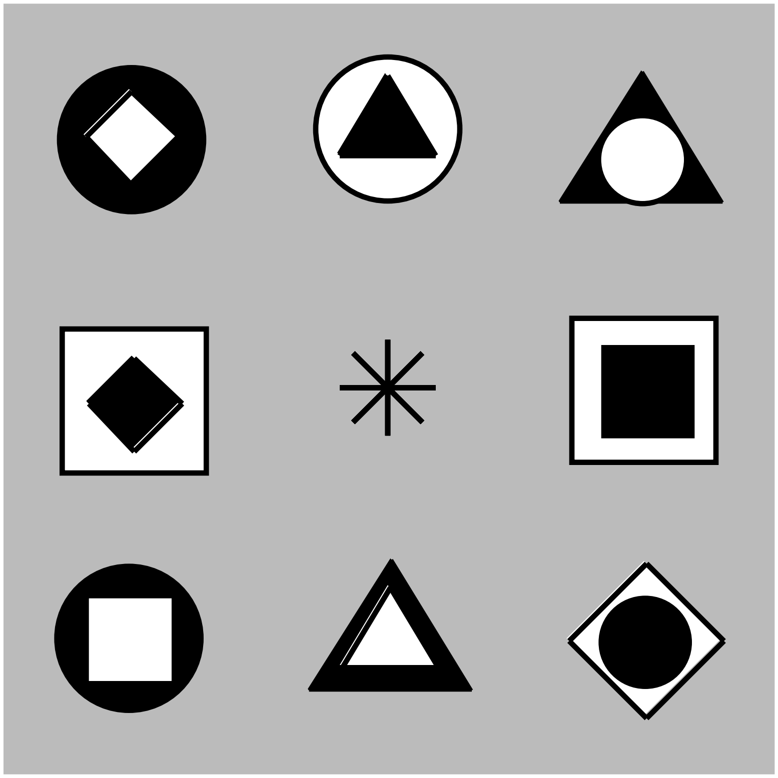


Figure One: To see *and* not to see, that is the question.

Now look for a black triangle surrounding a white square. The patterns in Figure One are deliberately large to circumvent the decline in visual resolution with eccentricity. You can see all of these patterns. Nevertheless, because your ability to process visual stimuli is limited, you do not immediately know that the first requested item is present at the lower left location and that the second requested item is not present at all. In order to perform the requested task, you had to restrict your visual processing to one item at a time. If you obeyed the instructions and kept your eyes on the central fixation point, you changed your processing of the visual input over time without changing the actual input.

Such acts of visual attention are the subject of this chapter. Because we cannot process everything, we must attend to something if we are to act on the basis of visual input. Attention is a thriving area of research. The goal of this chapter is to introduce the reader to those aspects of the field most relevant to vision research. In many cases, that introduction is quite cursory with the text serving as an annotated bibliography pointing the reader to the relevant papers. The chapter is divided into four sections:

A) Vision before attention - Looking at Figure One, you saw something before you knew if that something included a black triangle surrounding a white square. What visual information is available "preattentively", before attention is directed to a locus or an object?

B) Vision with attention - Most of vision research involves vision with attention since subjects are generally asked to perform some task while attending to some visual stimulus. How does attention alter a preattentive visual representation?

C) Vision after attention - Assuming that attention is restricted in space and time, does it leave any marks of its passage once it has been deployed away from a stimulus?

D) Vision without attention - In some situations it is meaningful to ask about the fate of stimuli that are never attended. This is related to, but not identical to, the question of vision before attention.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

1.1 Other resources

As noted, attention has become a very large topic in the past decade. This chapter, for instance, will introduce the reader to a substantial portion of the literature dealing with the "visual" side of "visual attention". Other sources provide coverage of other aspects of the field. Pashler (1997) has a written an excellent book for those interested in attention in its own right. Also recommended are Shiffrin's (1988) chapter in the 1988 edition of Steven's Handbook of Experimental Psychology, and Annual Review chapters by Kinchla (1992), and Egeth and Yantis (1998). Bundesen (1996) offers a concise review of formal models in a book that contains a considerable amount of useful information (Kramer, Cole & Logan, 1996). Reviews of specific topics can be found in Pashler (1998).

2. Vision before attention

Neisser (1967) introduced the idea of a "preattentive" stage of visual processing - vision before attention. Preattentive vision would be vision without capacity limitations. At the preattentive stage, everything could be processed at once across the entire visual field. What aspects of vision might have this property? Answering this question is not trivial because any time an experimenter asks a subject to respond to some visual stimulus, the subject will direct attention to that stimulus. It is probably impossible to get an explicit response from a subject based exclusively on the preattentive representation of a stimulus (see Section 5, "Vision without attention" for more on this issue).

2.1 The uses and interpretation of visual search experiments.

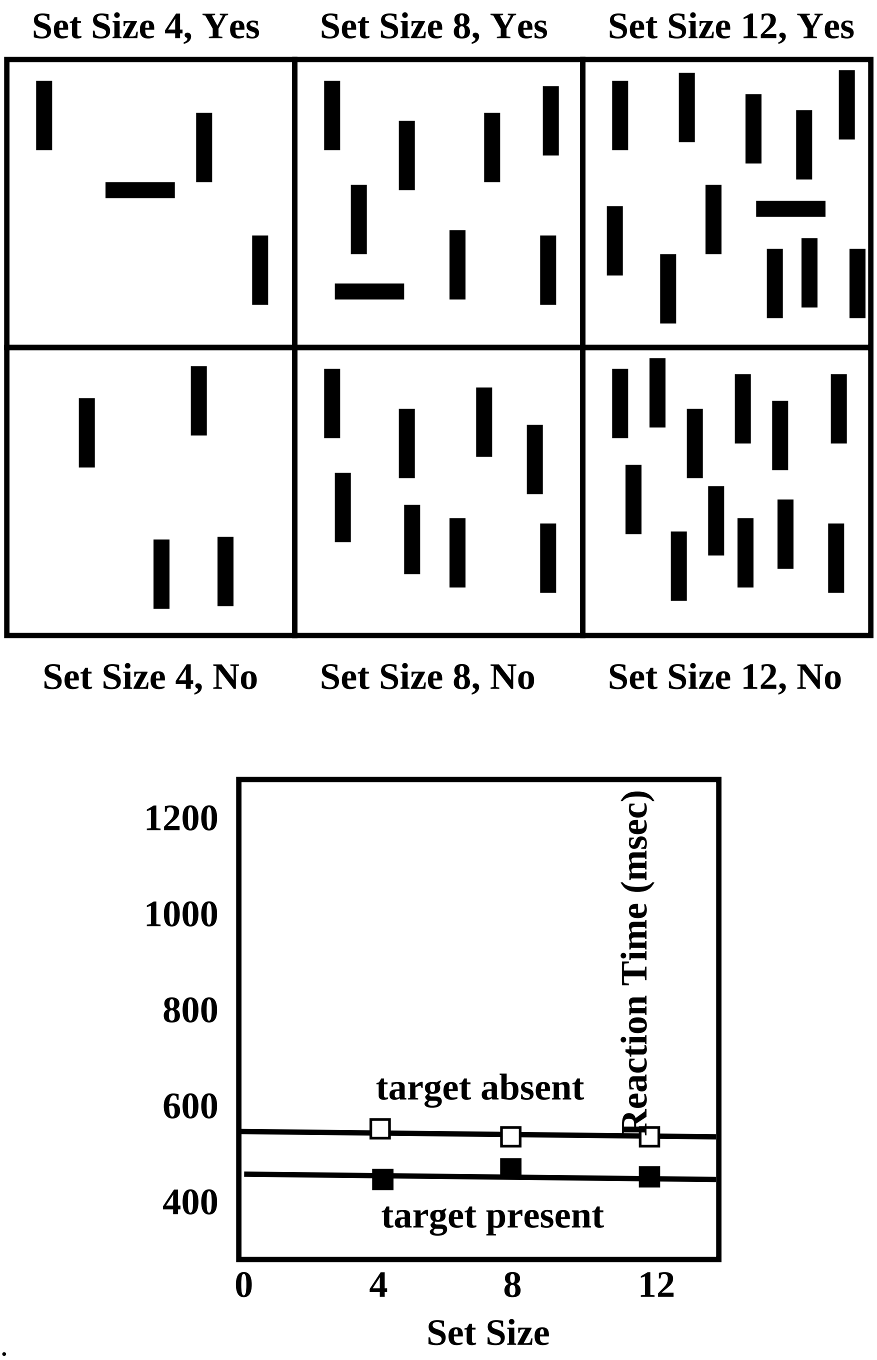
In trying to understand vision before attention, a more common strategy has been to look for the marks of preattentive processing in a task that requires both preattentive and attentive processing. One of the most useful methods is the visual search experiment. In a standard visual search experiment, the observer is looking for one target item in a display containing some number of distracting items. One of the attractions of this paradigm is that it brings a very common real-world visual behavior into the lab. In our day-to-day life, we frequently look for the keys, the socks, the can opener, or any of a host of visual targets in the cluttered visual display that is our world. The efficiency of a visual search can be assessed by looking at changes in performance; generally reaction time (RT) or accuracy, as a function of changes in the "set size"; the number of items in the display. These changes, in turn, can be used to make inferences about vision without attention. The slope of the RT X set size function is the most commonly used measure of the efficiency of visual search. Specifically, the deployment of visual attention can be "guided" with varying degrees of efficiency by the results of preattentive visual processing (Egeth, Virzi & Garbart, 1984; Hoffman, 1979; Wolfe, Cave & Franzel, 1989). As an example, consider a search for a red "F" among a number of other letters that can be either red or green. How is attention guided in such a search? For starters, preattentive processes are able to direct attention to objects so attention will not be deployed to random locations. It will be deployed to letters. Second, as will be discussed below, preattentive processes can guide attention on the basis of color information, so attention will be directed to red letters and not to green (Egeth et al., 1984). However, preattentive processes probably cannot read letters so attention will be randomly deployed through the set of red letters.

2.1.1 "Pop-out" and search asymmetries

As noted, different levels of preattentive guidance are reflected in the slope of RT x set size functions. If preattentive processing can be used to direct attention to a target without fail on every target-present trial, then there will be no effect of set size on search performance. In Neisser's terms, an item that can be detected on the basis of preattentive processing should "pop-out" of the display. An intuitively clear example would be a search for a red item among green distractors. The red target pops out and summons attention with minimal interference from the distractors. The slope of the RT x set size function will be near zero.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

The phenomenal experience of "pop-out" has a rather subjective quality to it, but RT and/or accuracy measures serve to operationalize it in visual search experiments. If the amount of time required to perform a visual search does not change as a function of the number of items in the display (the set size), then it is reasonable to propose that all items were processed at one time. Figure Two shows an example of a task that would produce evidence of this sort along with hypothetical data.



data.

Figure 2: Sample trials and hypothetical data for a search task that produces reaction times that are independent of set size. In a real experiment, the order of trials would be random.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Most examples of pop-out occur in searches in which the target is defined by a single basic feature. A limited set of basic features exists. The evidence for specific features in this set is found in Section 2.4.

An important characteristic of many feature searches is that they are asymmetrical. That is, if a search for A among B is efficient, it is not necessarily the case that a search for B among A is efficient (Treisman & Souther, 1985). In orientation, for example, it is easier to find a tilted line among vertical lines than vice versa. This can be understood in various ways. Treisman has argued that it is easier to find a deviation from a canonical stimulus (here, presumably, vertical) than it is to find a canonical stimulus among deviants (Treisman, 1985; Treisman & Souther, 1985). Another possibility, also introduced by Treisman, is that it is easier to find the presence of something than to find its absence. Continuing with the orientation example, visual search seems to treat all orientations as steep or shallow and as left or right tilted (Wolfe, Friedman-Hill, Stewart & O'Connell, 1992a). Consequently, a right tilted item would be readily found among verticals because it has a unique categorical attribute (right tilt). A vertical target among right tilted distractors is defined by the absence of tilt (if all items are "steep"). Consequently, it would be harder to find (Wolfe, 1994). Foster holds that search asymmetries in orientation are the by-product of broadly-tuned channels subserving orientation feature search (Foster & Ward, 1991a). There need not be a single account for all search asymmetries nor must these accounts be thought of as mutually exclusive. For instance, the orientation categories proposed by Wolfe et al. (1992) might be implemented as Foster’s broadly-tuned channels.

2.1.2 Inefficient "serial" searches

By contrast, if preattentive processing can do nothing more than segregate the items from the background, then attention will be deployed without further guidance over the set of items. As a result, performance will be strongly dependent on the set size. RT will increase and accuracy will decrease with set size. A search for a single target letter in a diverse set of distractor letters will probably proceed without preattentive guidance (but see Caerwinski, Lightfoot & Shiffrin, 1992; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). As a rough rule of thumb, such unguided searches will produce target-present slopes of 20-30 msec/item and target-absent slopes of at least twice that magnitude. Such data are roughly consistent with a serial, self-terminating search through the items but there are limited-capacity parallel accounts of the same data (Palmer, 1995; Townsend, 1971, 1976, 1990; Van Zandt & Townsend, 1993). See (Wolfe, 1997c) for a more detailed look at data of this sort.)

2.1.3 Conjunction searches

Between pop-out and a complete absence of guidance are cases, like the red "F" example given above, where preattentive processing provides imperfect guidance. The efficiency of search will be intermediate in these cases. As noted, search for a red F will be more efficient if half the letters are red and half are green than if all are red (Carter, 1982; Green & Anderson, 1956; Smith, 1962). In these cases, the deployment of attention can be restricted to a subset of items that preattentive processing can identify as likely to be targets.

The most important class of search tasks producing slopes of intermediate efficiency are conjunction searches. In conjunction tasks, subjects look for a target defined by a combination of basic features among distractors that share some but not all features with the target. An example might be a color X orientation conjunction search for a red vertical target among red horizontal and green vertical distractors. In her original Feature Integration Theory, Anne Treisman proposed that all conjunction searches were serial, self-terminating searches through all items that shared *any* features with the target (Treisman & Gelade, 1980). Subsequent research made it clear that this claim was too strong. First, as noted earlier, there were studies that showed that search could be restricted to subsets of the items - subsets defined by features like color (Egeth et al., 1984). Later studies showed that more than one feature at a time could contribute to the guidance of conjunction search (e.g. Alkhateeb, Morland, Ruddock & Savage, 1990a; McLeod, Driver, Dienes & Crisp, 1991; Nakayama & Silverman, 1986; Treisman & Sato, 1990; Wolfe, 1992b). The differences between Treisman's experiments and the later findings are discussed in Wolfe et al. (1989).

In an effort to explain efficient conjunction searches, it has been argued that some features are special in their ability to group distractors, segregate depth planes, or otherwise guide attention. This type of claim has been made for motion (McLeod et al., 1991; Nakayama & Silverman, 1986), stereopsis (Nakayama & Silverman, 1986), luminance polarity (Theeuwes & Kooi, 1994), and color, among others. As data have accumulated, it has become increasingly clear that efficient conjunction search is not restricted to searches involving only a few basic features. There is good evidence for efficient conjunction searches involving orientation, curvature (Wolfe, Yee & Friedman-Hill, 1992b), and, indeed, almost any feature that has been tested. Rather than invoking special attention-guiding abilities for one feature or the other, it might be better to assume that all the preattentive features discussed in the next section have some ability to guide attention but that some features provide better guidance than others. The ability to guide attention in conjunction search seems to be related to the salience of the stimulus differences involved (Wolfe et al., 1989). That is red items are easier to segregate from green items than from orange (Duncan & Humphreys, 1989). To make claims for the special status of one type of feature, stimulus salience would need to be equated across features. Nothdurft (1993c) has provided a useful method to do this but the issue has not been pursued in conjunction search studies.

While guidance of visual search can be used as evidence for preattentive processing of the guiding attribute, the reverse is not true. Failure to find guidance, in the form of efficient visual search, is not definitive evidence that a property is not processed preattentively. It is theoretically possible to have a preattentive process capable of responding to some stimulus property but unable to provide guidance for the subsequent deployment of attention. As an analogy, consider trying to describe a sunset to a friend on the other side of the country. Your description can never quite capture the richness and detail of your perception. Your inability to convey the exact shading of the sky does not mean that you did not see it. The same logical possibility exists in inferences about preattentive vision based on visual search. If a search experiment produces RT x set size slopes near zero, as in Figure 2, that is evidence that preattentive processes are sensitive to the differences between targets and distractors. If the slopes are not near zero, that is evidence that preattentive processes cannot direct attention based on the differences between targets and distractors. Those differences might still be registered preattentively but be unavailable for export.

2.2 Typical conditions and pitfalls in visual search tasks.

That cautionary note notwithstanding, there is a great deal that we can learn about preattentive processing from visual search experiments. In this section, we will address a few methodological issues before turning to the results of search studies.

In a typical visual search task, subjects would run several hundred trials of the sort shown in Figure 2. A range of set sizes would be tested with the set size on each trial chosen randomly. Target presence or absence would also vary from trial to trial. Usually targets are presented on 50% of trials. Items are positioned at random in the visual field with target position, likewise, random. Reaction time and accuracy are measured. Subjects are usually instructed to keep error rates low in these experiments where "low" means something like "below 10%". The slope of the RT x set size function is the main measure of interest though the mean RT and/or the y-intercepts of RT x set size function may also be useful. In our lab, we have found that the statistical reliability of slopes from individual subjects running 300 or 400 trials is quite low (O'Neill & Wolfe, 1997). Consequently, statements about slopes should be based on data from multiple subjects (Ten is a reasonable sample.) or on quite massive amounts of data from single subjects (thousands, not hundreds of trials).

The linearity of RT x set size functions is often asserted with more vigor than data. Typical search experiments use three or four set sizes. Regression coefficients based on linear fits of three points will be high for almost any set of three monotonically increasing values. Moreover, linearity over a relatively small range of set sizes (typical in search experiments) does not guarantee linearity over a large range (for a clear illustration of this point see Carrasco, Evert, Chang & Katz, 1995).

The distribution of RTs for a single set size are generally not normally distributed. Most commonly, the distributions are positively skewed. Therefore, slopes based on simple means may be somewhat misleading since the RT means may be poor representatives of the central tendency of the data. Common solutions to this problem include using median RTs and using the mean of log transformed RTs, but examination of the actual distributions seems preferable to blind application of any solution.

Probably the greatest opportunities for error in visual experiments lie in the creation of the stimuli rather than the analysis of the data. Efficient, preattentively guided search can be masked by several factors. The most basic of these involve issues of resolution and eccentricity. If items need to be foveated before targets can be discriminated from distractors, then slopes are going to be steep. Indeed, any time slopes of RT x set size functions approach 100-150 msec/item for target present trials and twice that for target absent, one should suspect an eye movement artifact. If the stimuli are of an adequate size, then it should be possible to identify a single item as target or distractor in a brief (e.g. 200 msec) exposure at any location in the display. Given adequately large stimuli, it is probably not necessary to tightly restrict eye movements. Zelinsky and Sheinberg (1997) have shown that the pattern of RTs is very similar under conditions of both free eye movement and rigorous fixation.

Even with large stimuli, there are very substantial effects of eccentricity on RT (Carrasco et al., 1995; Chun & Wolfe, 1996; Sanders, 1993; Wolfe, O'Neill & Bennett, 1997). In some cases, these can be eliminated by scaling stimuli with a cortical magnification factor (Carrasco & Frieder, 1997). There is evidence that eccentricity effects are not isotropic. Unfortunately, the literature is not clear on the nature of the anisotropy. Right field superiority has been found (Efron & Yund, 1996; Yund, 1996; Yund, Efron & Nichols, 1990) as have lower field (He, Cavanagh & Intriligator, 1996) and upper field superiority (Previc, 1996; Previc & Blume, 1993). The topic is interesting in its own right but for purposes of standard search experiments the message is that the distribution of target locations should be the same as the distribution of distractor locations in order to avoid systematic errors.

In search experiments, multiple items are presented at one time. This raises the possibility of lateral interactions between items, notably mutual interference (Berger & McLeod, 1996; Cohen & Ivry, 1991). These effects of crowding are more marked in the periphery than they are near the fovea (He et al., 1996). This becomes a methodological problem in visual search experiments because, as a general rule, density increases with set size (Cohen & Ivry, 1991). One can hold density constant but then it becomes necessary to allow mean eccentricity to increase with set size (clearly undesirable) or to position regions of uniform density at different locations in the visual field from trial to trial. This latter method is useful when the stimuli are briefly exposed, precluding eye movements. Otherwise, the eyes have a tendency to move to the center of gravity of the display (Findlay, 1995; Zelinsky, Rao, Hayhoe & Ballard, 1996). This introduces an eccentricity artifact as if all displays were centered on fixation. In a generic search task, it is probably wise to space items so widely that crowding effects are unimportant even at the highest set sizes and densities.

2.3 Texture segmentation and visual search

Done correctly, visual search experiments can be used to identify properties of the visual input that are processed prior to attention. The properties have been called "basic" or "preattentive features". As shown in Figure 2, highly efficient search (RT x set size slopes near zero) is the mark of preattentive processing. However, a slope near zero, by itself, is not definitive evidence that the target differs from distractors on the basis of a preattentive feature. Evidence from some converging operation is desirable before enrolling a feature in the ranks of the preattentive (Garner, Hake & Eriksen, 1956). One of the most useful converging methods is texture segmentation (Beck, 1966a, 1966b, 1982; Julesz, 1981; Treisman & Gelade, 1980; see also Trick & Enns, 1997). In texture segmentation tasks, a target *region* of items differs from the background items. That region either does or does not "pop-out" as shown in Figure 3.

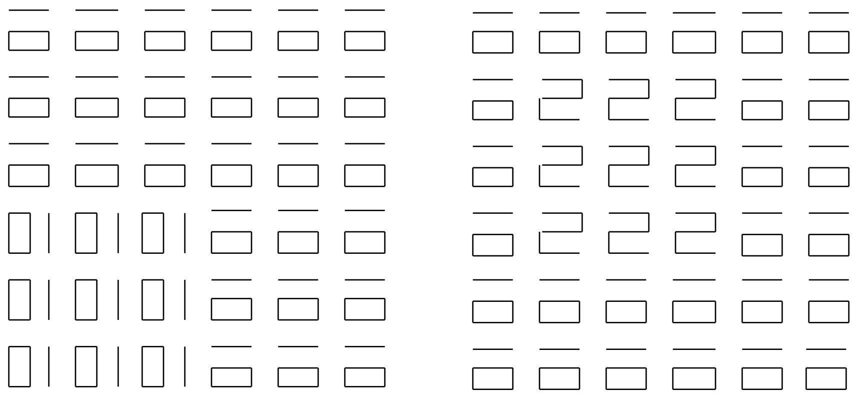


Figure 3: Texture segmentation (after Julesz, 1981)

In 3a, a difference in orientation causes the lower left region to clearly segment. In Figure 3b, the difference between ⊏ and ⊏ is much less evident. To quantify the degree of texture segmentation, the usual methods involve brief presentation of the patterns in order to prevent item by item scrutiny. Subjects are asked to make a forced-choice localization of the target region or, perhaps, an identification of the shape of the region (vertical, horizontal, etc) (Bergen & Julesz, 1983).

Search and texture segmentation sound very similar, but they are not identical as Figure 4 illustrates.

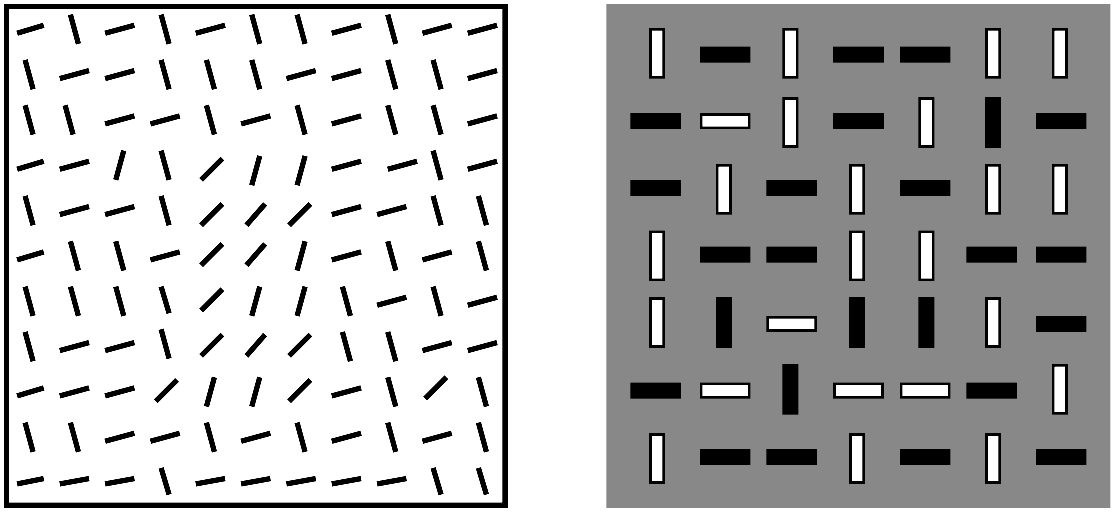


Figure 4 - 4a shows an example of good texture segmentation with difficult search while 4b shows efficient search without good texture segmentation (after Wolfe, 1992a).

In Figure 4a, the targets are tilted 15 and 45 deg to the right of vertical among distractors tilted 15 deg to the left and 75 deg to the right. It is not hard to see that there is a vertical texture patch but it quite laborious search is required to find the isolated 15 and 75 deg targets (row 4 - column 3 for one, row 9, column 10 for the other). In Figure 4b, the targets are white horizontal and black verticals. Isolated examples of these are found quite efficiently but it will take considerable scrutiny to determine the orientation of the texture region defined by the appropriate conjunctions of color and orientation. Stimulus properties that produce both efficient search and effortless texture segmentation are good candidates for preattentive features (Donk & Meinecke, 1997; Nothdurft, 1994; Wolfe, 1992a).

2.4 Preattentive Features

This section will review the data supporting specific preattentive features. A somewhat more extensive review of this topic can be found in Wolfe (1997b).

COLOR

Color has long been accepted as a preattentive feature (Bundesen & Pedersen, 1983; Carter, 1982; Farmer & Taylor, 1980; Green & Anderson, 1956; Smith, 1962; Williams, 1966a). Search for a target color among homogeneous distractors is efficient as long as the target and distractor colors are not too similar (Nagy & Sanchez, 1990; Nagy, Sanchez & Hughes, 1990). With multiple distractor colors, search is efficient if a line can be drawn through color space separating the target and distractors colors (linear separability Bauer, Jolicœur & Cowan, 1996a; Bauer, Pierre & B., 1996b; D'Zmura & Lennie, 1988) or if the colors are widely separated (Duncan, 1988 ; Smallman & Boynton, 1990; Wolfe et al., 1990). With widely separated colors, some colors may be more basic than others. Thus, for instance, purple may be represented as red and blue in the preattentive guidance of attention (Moraglia, Maloney, Fekete & Al-Basi, 1989; Treisman, 1985; Treisman & Gormican, 1988). Color space is three dimensional. There is some evidence that the achromatic dimension is treated differently in visual search (Theeuwes & Kooi, 1994).

Preattentively processed color information is readily used to select items for subsequent, attentional processing (Egeth et al., 1984; Kaptein, Theeuwes & Van der Heijden, 1994; Poisson & Wilkinson, 1992; Wolfe et al., 1989; Zohary, Hochstein & Hillman, 1988). This selection can be seen physiologically in, for example, area V4 (Motter, 1994a).

Because it is so effective, selection by color is common in the design of visual displays (e.g. Backs & C., 1995; Van Orden, 1993). Shih and Sperling (1996) have argued that this selection is a selection of colored locations (or objects) rather than a selection of color in some more abstract sense.

In general, it is difficult to use two colors to guide attention simultaneously (Wolfe et al., 1990). There are some exceptions to this rule (Grabowecky & Khurana, 1990; Heathcote & Mewhort, 1993). Notably, search for items defined by the conjunction of two colors may improve markedly with practice (Ponte, Rechea, Sampedro & Carrasco, 1997). In addition, while it may be hard to find the item that is "red and yellow", it is substantially easier to find a red "object" surrounding a yellow "part" (Bilsky & Wolfe, 1995; Wolfe, Friedman-Hill & Bilsky, 1994).

Finally, there is mixed evidence for a preattentive ability to detect a change in color. D'Zmura and Mangalick (1993) find that subjects can search efficiently for a target that is undergoing a smooth color change different from that of the distractors. However, Theeuwes (1995) finds that subjects cannot search efficiently for an abrupt change in color. The meaning of these differences is presently unclear, though D'Zmura and Mangalick (1993) were simulating conditions of changing illumination and that more natural situation may be critical here.

ORIENTATION

Orientation differences can guide the deployment of attention. A target will pop-out of a field of homogeneous distractors if the difference between target and distractor orientations is large enough (15 deg is a good rule of thumb). Foster and his colleagues have collected the most systematic data on this point (Foster & Ward, 1991a, 1991b; Foster & Westland, 1993). Work by Moraglia (1989a) and, much more extensively by Nothdurft makes it clear that it is local differences in orientation that are critical in these cases (Luschow & Nothdurft, 1993; Nothdurft, 1993a, 1993b, 1991b, 1992, 1993c) (see also Bravo & Blake, 1992; Landy & Bergen, 1991). Converging evidence for the featural status of orientation is readily available from texture segmentation studies (e.g. Landy & Bergen, 1991; Nothdurft, 1991b).

When more than one distractor orientation is present, several factors determine the efficiency of search (Alkhateeb, Morris & Ruddock, 1990b). One of these is the categorical status of the items. For the purpose of guiding attention, orientations seem to be categorized as "steep", "shallow", "left-tilted" and "right-tilted". It appears to be quite easy to search for a target if it is categorically unique and quite difficult if it is not. For example, search for a 10 deg target among +/- 50 deg distractors is quite efficient. With vertical defined as 0 deg, the 10 deg target is the only "steep" item in the display. Search for the same 10 deg target among +70 and -30 deg distractors in less efficient because -30 deg items share "steepness" with the target and the +70 deg items share "rightness" (Wolfe et al., 1992a). Foster's group has proposed a set of broadly tuned filters that that perform operations similar to the proposed categorization of orientations (Foster & Ward, 1991b; Foster & Westland, 1995) but see (Mannan, Ruddock & Wright, 1995).

These results can be thought of in terms of target-distractor and distractor-distractor similarity. Duncan and Humphreys (1989) argue that search efficiency increases with distractor-distractor similarity. The more homogeneous the distractors, the more efficient the search. Search efficiency decreases with target-distractor similarity. The Wolfe et al. (1992) results show that similarity is modulated by categorical status as well as by angular separation. The similarity of orientations is also modulated by symmetry relations. In visual search, symmetrical orientations are more similar than their simple angular separations would suggest (Wolfe & Friedman-Hill, 1992a). Additionally, efficient orientation search can be based on unique angular relationships between items (Wolfe & Friedman-Hill, 1992b). Asymmetries in orientation search were discussed in Section 2.1.1 above.

Efficient orientation search can be performed with items that are created from a wide range of different surface media. The items can be defined by luminance, color, texture, motion, or other, smaller oriented lines (Bravo & Blake, 1990; Cavanagh, Arguin & Treisman, 1990; Luschow & Nothdurft, 1993). All of this suggests that the preattentive representation that supports orientation search comes relatively late in visual processing. Physiological evidence suggests that early processing (primary visual cortex) can represent luminance-defined orientation but not the other methods of stimulus generation (Von der Heydt, Peterhans & Baumgartner, 1984).

There are some oriented items that will not support efficient search. For example, Gilchrist et al. (1997) found that subjects could search efficiently for an oriented target defined by two white circles or by two black circles. However, if the item was defined by circles of different polarity, one white and one black, then search was inefficient. Interestingly, if the circles were replaced by squares, efficient search became possible. Apparently the colinearity of the edges of the squares could overcome the preattentive resistance to polarity reversal (see also Enns & Kingstone, 1995).

It does not seem to be possible to guide attention to two orientations at the same time (Bilsky & Wolfe, 1995; Wolfe et al., 1990). Finally, there is some indication that the preattentive coding of orientation and size (or spatial frequency) may not be independent (Sagi, 1988).

CURVATURE

Curvature has been proposed as a preattentive feature (Foster, 1983; Treisman, 1986). Search for curve among straight is efficient as is search for a curve among its 180 deg rotation (left vs right, up vs down). The claim of featural status has support from texture segmentation experiments (Simmons & Foster, 1992). Curvature may not be a terribly robust feature. If the curves form the mouths of schematic happy and sad faces, efficient search does not appear to be possible (Nothdurft, 1993d), possibly because the other components of the face mask the curvature cue.

The status of curvature as a visual feature has been a matter of debate for many years in other contexts (Blakemore & Over, 1974; Riggs, 1973 ; Stromeyer & Riggs, 1974). The heart of the argument concerns whether curvature is coded by the visual system as curvature *per se* or merely as a local change in orientation. In visual search, it appears that curvature is more than just local orientation change (Wolfe et al., 1992b).

SIZE

In thinking about size as a basic feature, there are several different but related senses of the term that must be considered. In visual search, size can refer to the spatial extent of an item. There is good evidence for the featural status of size in this sense. Search for the biggest item is particularly efficient (Bilsky, Wolfe & Friedman-Hill, 1994; Dehaene, 1989; Stuart, 1993; Williams, 1966b). In unpublished work, we have found that searches for the biggest and smallest items are efficient enough but search for the medium-sized target among big and small distractors is inefficient. Again there is support from texture segmentation (Wolfe, Chun & Friedman-Hill, 1993).

Size can also refer to spatial frequency. Efficient search can be based on patches of the same angular subtense if they contain gratings of different spatial frequency (Verghese &

Nakayama, 1994). As with size, the extremes of coarsest and finest are relatively easy to find, while an intermediate frequency is hard to find among coarser and finer distractors (Bose and Wolfe, unpublished). As noted above, it may be difficult to treat spatial frequency and orientation as independent features (Moraglia, 1989b; Sagi, 1988). There is support from texture segregation for a preattentive role for spatial frequency (Julesz & Papathomas, 1984).

Spatial scale is the final sense in which size enters into research on spatial attention. It is intuitively clear that scale can be an important factor. If you are looking at someone, you can attend to the person, the face, the nose, or the spot on the end of the nose; all while having the same visual stimulus present in the field and all while having attention centered on the same location in that stimulus. In the laboratory, work on spatial scale has rarely involved such natural stimuli. More commonly, the stimuli have been forms composed of other forms as shown in Figure 5.

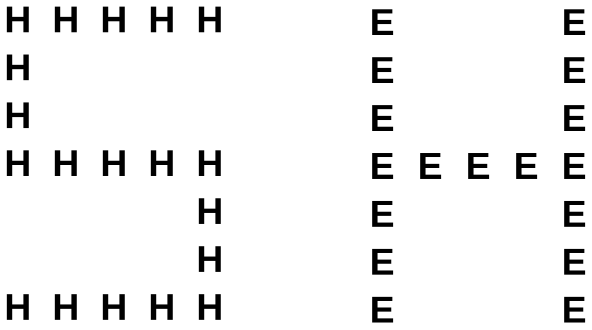


Figure 5: (Global/local stimuli after Navon, 1977)

Navon (1977) proposed that processing of such stimuli proceeds from the global to the local level (see also Paquet, 1992). That appealing simple story gave way to the more complicated realization that so-called "global precedence" could be modulated by the size and spatial frequency content of the stimuli (Kinchla & Wolfe, 1979; LaGasse, 1993; Lamb

& Robertson, 1990; Lamb & Yund, 1993) as well as by attentional factors (e.g. cueing Robertson, Egly, Lamb & Kerth, 1993). In visual search experiments, Enns and Kingstone (1995) found relatively efficient search for local forms with less efficient search for global. They argued that an "attention-demanding grouping stage" was required to put together global stimuli of the sort shown in Figure 5. Saarinen (1994) reported a global precedence effect with globally oriented stimuli composed of locally oriented stimuli. However, this result may be an artifact of the particular orientations used (Durgin & Wolfe, 1997). Completing this somewhat confused picture, there is evidence that attention can be directed to two scales at once but with some cost (Farell & Pelli, 1993; Verghese & Pelli, 1994) but see (Saarinen, 1995).

This global-local literature (pre-1992) has been well reviewed by Kimchi (1992). For present purposes, perhaps the safest conclusion to be drawn from these experiments is that, since attention can be directed on the basis of scale, scale must be represented preattentively. This would be consistent with our finding that visual search can be modified by the hierarchical structure of items (Wolfe et al., 1994). It is less reasonable to conclude that attention must be directed to one level in a display before another. The findings are simply too diverse.

MOTION

Moving targets pop-out of a field of stationary distractors (Dick, Ullman & Sagi, 1987). In recent, as yet unpublished work, we have looked simple feature search in five conditions with results as shown below:

Target	Distractors	Target-present slope	Target-absent slope
linear motion	stationary	-1.2	-1.4
brownian motion	stationary	-0.7	-0.4
stationary	linear one direction	6.5	10.5
stationary	linear multiple directions	12.9	25.6
stationary	brownian motion	13.0	18.7

Table 1 - Results of simple motion search experiments. Slopes are given in msec/item.

Individual spots could move in a single direction throughout a trial or their motion could change randomly from frame to frame. Search for random or linear motion among stationary distractors was very efficient. Search for the absence of motion is less efficient. This asymmetry was most marked when the distractor motion was random. This probably reflects the fact that attention is attracted to points of local change (Nothdurft, 1991a, 1993c) and the random distractor motion creates the greatest quantity of irrelevant local motion contrast.

There have been some investigations of visual search using other motion displays, notably optic flow displays that simulate observer motion through a stationary world (Royden, Wolfe, Konstantinova & Hildreth, 1996, 1997). In these studies, subjects were able to search with reasonable efficiency for spots that were stationary in the stimulus even though multiple directions of motion were present in the distractors. At least two interpretations of these data suggest themselves. If the display was interpreted as a stationary world seen by a moving observer, then the physically stationary target would represent a moving, attention-grabbing stimulus in the world. Alternatively, since motion in optic flow stimuli is locally quite homogeneous, the stationary item might simply represent the locus of the greatest local change in motion. Control experiments seem to favor the latter account but the issue is not settled.

In optic flow, the entire field moves in a coherent manner. It is also possible to create items that each have their own pattern of expansion or contraction. With these localized flow patterns, we can ask if an expanding item pop-outs from a collection of contracting items or vice versa (Obviously, it is necessary to control for uninteresting size artifacts.) It had been argued that all such searches were inefficient (Braddick & Holliday, 1991). However, more recent work finds that two-dimensional patterns of expansion are found efficiently among contracting distractors while contracting targets remain hard to find among expanding distractors (Takeuchi, 1997).

There is an asymmetry in speed detection with fast stimuli among slow found more efficiently than slow among fast (Ivry, 1992). Driver et al. (1992a) report on a series of experiments revealing the rather complex relationship of speed and direction in visual search. In apparent motion, short-range apparent motion (or whatever one cares to call it - Cavanagh & Mather, 1989) supports efficient search while long-range does not - (Dick et al., 1987; Horowitz & Treisman, 1994; Ivry & Cohen, 1990). Motion defined by equiluminant stimuli does not support efficient search (Luschow & Nothdurft, 1993) nor does motion with bicontrast dot (Horowitz & Treisman, 1994).

When it comes to guiding attention toward more complex targets, motion is one of the most effective of the preattentive features. Knowing the motion of a target speeds search (Berbaum, Chung & Loke, 1986). Most of the evidence for the guiding power of motion comes from conjunction searches (McLeod, 1993; McLeod, Driver & Crisp, 1988; McLeod et al., 1991; Nakayama & Silverman, 1986) see also (Kawahara, 1993). A number of studies have concentrated on the tendency of moving stimuli to form coherent groups (Driver, McLeod & Dienes, 1992b; Duncan, 1995). Some of the complexities of the relationships between features are revealed in series of papers on orientation X motion conjunctions. In one task, the target might be a moving item of orientation A among stationary items of orientation A and moving items of orientation B. In another task, the target could be stationary A among moving A and stationary B, and so forth. Control conditions assessed the efficiency of the relevant orientation features searches (orientation A among B and vice versa, moving among stationary and vice versa). Driver and McLeod (1992) found that, if the orientation feature search was efficient, then the conjunction task was easier if target was in motion. If orientation task was inefficient, then the conjunction task was easier if the target was stationary. Müller and Maxwell (1994) failed to replicate this search asymmetry. Berger and McLeod (1996) argued that this was due to differences in item density, though Müller and Found (1996) disagreed. This somewhat arcane disagreement is worth pausing over because it illustrates the fact that the finer details of preattentive processing are hard to infer from single experiments. Visual search is a signal detection problem with the properties of the target providing the signal and the properties of the distractors and their interrelationships providing the noise (e.g. see discussion in Eckstein, Thomas, Palmer & Shimozaki, 1996; Hübner, 1993; Verghese & Nakayama, 1994; Wolfe, 1994). Seemingly simple changes in something like the orientation of half of the items may have complex consequences. Firm conclusions may require evidence from a series of experiments using different stimuli - though, in some case, the definitive answer may not be worth the effort.

DEPTH CUES

The third dimension of space is represented in preattentive vision. This can be seen in the ability of various depth cues to guide and modulate the deployment of attention. Stereopsis will support efficient search (Nakayama & Silverman, 1986). In fact, Julesz's classic random dot stereograms can be seen as texture segmentation evidence for the preattentive calculation of disparity (Julesz, 1962, 1964, 1971). Some of the details of preattentive processing of disparity are worked out in the visual search experiments of O'Toole and Walker (1997) (see also Chau & Yei-Yu, 1995). These studies used stimuli in the frontal plane - one disparity per stimulus. Search experiments also reveal preattentive sensitivity to changes in depth within a stimulus. When targets and distractors differ in the tilt out of the frontal plane, efficient search is possible (Holliday & Braddick, 1991) (see also Epstein & Babler, 1990; Epstein, Babler & Bownds, 1992).

Depth relationships within items are at the heart of most other demonstrations of preattentive processing of the third dimension. Preattentive processes seem to be able to distinguish objects that appear concave from those that appear convex using shading as the cue to depth (Kleffner & Ramachandran, 1992; Ramachandran, 1988; Snyder & Barlow, 1988) (see also Aks & Enns, 1992; Braun, 1993). These studies use circular patches filled with a grayscale gradient, brighter on top and dimmer on bottom (or vice versa). Left-right gradients do not work as well suggesting a bias to assume a light source shining from above (Sun & Perona, 1996b). Step changes that do not look like shading at all, will also support reasonably efficient search (Heathcote & Mewhort, 1993; Kleffner & Ramachandran, 1992). This could cause one to wonder if shading is, indeed, the cue in these experiments. In other contexts, shading information does seem to be unambiguously useful in distinguishing targets and distractors (Enns & Rensink, 1990a; Sun & Perona, 1996a) and there is evidence that preattentive processes are sensitive to the physical properties of shadows (Rensink & Cavanagh, 1993).

Enns and Rensink have done a series of experiments showing that the preattentive processes can interpret line drawings as simple 3D shapes (cubes, etc) and can base visual search performance on properties like the orientation of a bar in depth (Enns, 1992; Enns & Rensink, 1990b, 1991, 1993). They used RT measures. Sun and Perona (1996a) used accuracy measures to confirm and extend these results. Like other features, preattentive processing of depth cues produces search asymmetries. For example, finding an upward tilted cube among downward tilted cubes is easier than downward among upward (Von Grünau & Dubé, 1994)

Evidence for preattentive processing of occlusion comes from interesting work by Rensink and Enns (1995) showing that preattentive processes cannot ignore the results of occlusion. Thus, a 1 deg long line is treated as a 1 deg long line even if a portion of the middle of that line is occluded.

Further evidence for the preattentive processing of depth information comes from experiments on the deployment and spread of attention. Several experiments show an ability to allocate attention to locations cued in depth (e.g. Andersen, 1990; Downing & Pinker, 1985). Other experiments show restriction of attention to surfaces defined by stereodisparity (He & Nakayama, 1994a, 1994b, 1992).

VERNIER

Fahle has shown that vernier offsets can be found efficiently and that this ability is not reducible to a form of orientation search (Fahle, 1991, 1990).

LUSTRE

Wolfe and Franzel (1988) have shown that binocular lustre could be found efficiently. Binocular lustre, produced by putting a dark field in one eye and a light field at the corresponding location in the other (Helmholtz, 1924; Tyler, 1983), is just one way of making a surface appear to be shiny. Presumably, the preattentive feature is the surface property of shininess and not something specific to binocular visual processing though this has not been tested. Other dichoptic properties like binocular rivalry (Blake, 1989; Wolfe, 1986) do not support efficient search (Wolfe & Franzel, 1988).

ASPECTS OF SHAPE

Shape is the holy grail of preattentive features. Like the grail of myth, it seems clearly present yet frustratingly illusive. Some aspects of spatial configuration are available to preattentive processes but it has proven rather difficult to specify exactly which ones. Terms like shape and form are often used rather loosely. For instance, a study could involve search for a moving X among stationary Xs and moving Os. This task might be described as a search for a conjunction of motion and form (McLeod et al., 1988) but X's differ from O's in a number of ways. O's are curved, closed, and without terminators. X's are composed of straight lines, they do not form closed regions, and they have 4 terminators. Which of these aspects is available preattentively?

Julesz and his colleagues tried to account for shape effects with an argument that preattentive vision could only sense differences in the first-order statistics of patterns. Texture segmentation could not be supported by texture elements that differed only in 2nd order or higher properties (Caelli, Julesz & Gilbert, 1978; Julesz, Gilbert, Shepp & Frisch, 1973). Exceptions to this rule gave rise to Julesz's texton theory (Bergen & Julesz, 1983; Julesz, 1981, 1984, 1986; Julesz & Bergen, 1983). Here he argued for a limited set of shape primitives, like line termination, whose presence could be detected preattentively.

Terminators

There is good support for the preattentive processing of line termination (Bergen & Julesz, 1983; Julesz, 1984). For some pairs of target and distractor, it can be a little difficult to decide if line termination or closure is the critical feature in a search. For example, consider the difference between and "O" and a "C". Is the "O" closed or does the "C" have a pair of line terminators? If we accept Treisman's analysis of search asymmetries, then, in the case of "C"s and "O"s, the evidence comes down in favor of line termination. Treisman has argued that it is easier to find the presence of a feature than to detect its absence (Treisman & Gormican, 1988). Thus, given the finding that it is easier to find a "C" among "O"s than vice versa, it follows that the "C" must carry the feature. In this case, that would appear to be line termination.

While the presence of a terminator may be easy to detect among its absence, the quantity of terminators is not as useful in guiding deployment of attention. Taylor & Badcock (1988) found that search was inefficient when a target with 7 terminators was presented among distractors with only 2. The data of Cheal and Lyon (1992) complicate the picture further. They obtained shallower target trial slopes for an "S" among "E"s (2 vs 3 terminators) than for an "E" among "S"s (3 vs 2 terminators). When Enns (1986) used elongated stimuli, the ability to search for terminators was impaired.

Intersection and filter models of texture segmentation

Julesz proposed that intersections served as textons. The classic demonstration is shown in Figure 6:

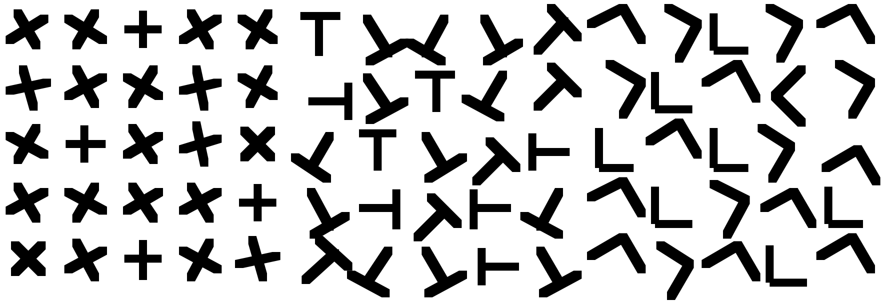


Figure Six: The border between "+"s and "T"s is clearer than that between "T"s and "L"s

Each of the elements in the figure is composed of a pair of orthgonal lines of equal length, yet it is clear that the “+”s form a discrete region while the border between the “T”s and the “L”s is not easy to see. Bergen and Adelson (1988) questioned the need to explain these texture segmentations by invoking texture primitives like textons. Like others, they suggested that spatial filters of the sort found in early vision would do the job. (see also Graham, Venkatesan & Sutter, 1993; Gurnsey & Browse, 1989; Keeble & Morgan, 1993; Malik & Perona, 1990). Julesz and Krose (1988) created textures that they argued could not be explained with standard filtering models. He and Nakayama (1994b) argued a similar point with a different set of experiments. The debate has a certain similarity to the old debate about whether vision was a matter of feature detectors or channels - one of those either-or debates where later generations find it a bit difficult to see exactly what the argument was about (Weisstein, 1973). If we take as given that spatial filters/channels are the front end of the visual system, then, if a “T” is to be discriminated from a “+”, that information must be present in some form in those channels. For our purposes, the question is whether intersections are represented preattentively and the evidence is equivocal.

Closure

The preattentive processing of closure is seen less in its ability to support efficient search in its own right and more in its ability to make other searches efficient. For example, consider the searches in Figure Seven, derived from the work of Elder and Zucker (1993, 1994, 1998). The search for brackets pointing in at each other among brackets pointing out is made easier if the brackets are clearly part of the same object. A similar point is made by (Donnelly, Humphreys & Riddoch, 1991)

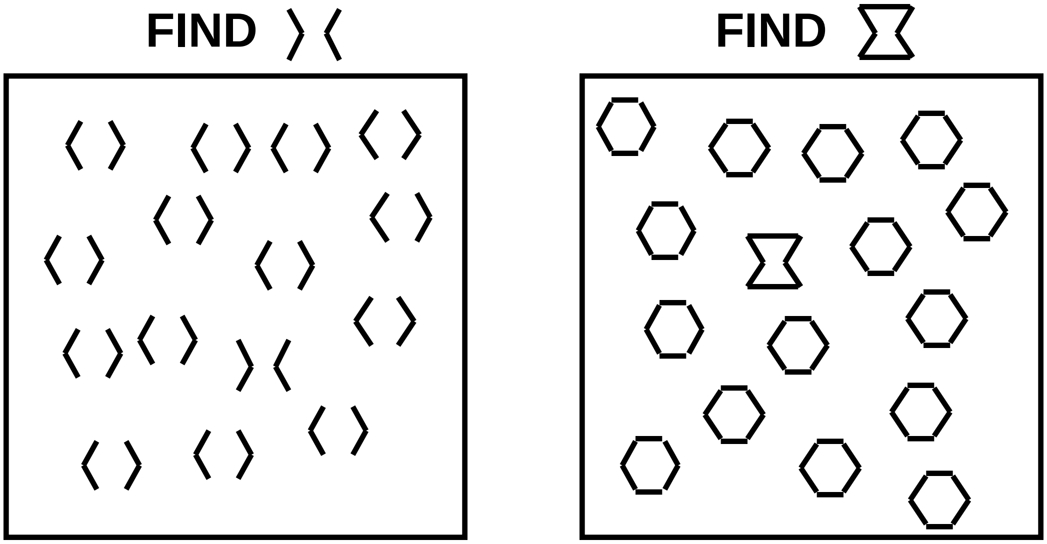


Figure Seven - It is easier to determine the relationship between two local elements if they are part of the same object (after Elder and Zucker, 1993)

Topology

Chen and his colleagues have argued that the topological status of objects is available preattentively. For instance, targets with holes can be found efficiently among distractors without holes. (Chen, 1982, 1990; Chen & Zhou, 1995) but see (Rubin & Kanwisher, 1985).

2.5 The Preattentive Processing of Objects

The status of closure and topology raise the more general issue of the role of objects in preattentive vision. In visual search, there is a good case to be made that attention is deployed from object to object rather than from location to location or feature to feature. In most laboratory search tasks, this is an idle distinction since objects and their features occupy unique locations. However, the distinction becomes important in the real world where objects and observers move. These real-world considerations make an *a priori* argument for attention to objects. It is hard to imagine that it would be useful to have an attentional system that deployed attention to the location of a toddler at one moment but then left attention at that location while the toddler toddled off. A substantial number of experiments have been devoted to the ability to use attention to track target objects among distractor objects while all are moving (e.g. Culham & Cavanagh, 1994; Intriligator, Nakayama & Cavanagh, 1991; Pylyshyn & Storm, 1988; Yantis, 1992).

Evidence for the preattentive status of objects comes from experiments that show that object status modulates visual search or some other attention-demanding task. For instance, it is much easier to determine the relationship of two properties if they are part of the same object than if they are not (Duncan, 1984; Duncan, 1993) (see also Lavie & Driver, 1996; Vecera & Farah, 1994). In these experiments, features maintain the same spatial relationships whether they are one object or two. This suggests that attention is directed to objects and that it can be spread across a pair of objects only with difficulty. If attention is being directed to an object, it follows that the object was represented preattentively in some fashion. The work of Baylis and Driver (1993) makes a similar point, using figures rather like those shown in Figure Eight. In this case, the task was to determine if the left vertex was above or below the right. He found that this task was much easier if the vertices were part of the same object (For further discussion of these issues see Baylis, 1994; Gibson, 1994).

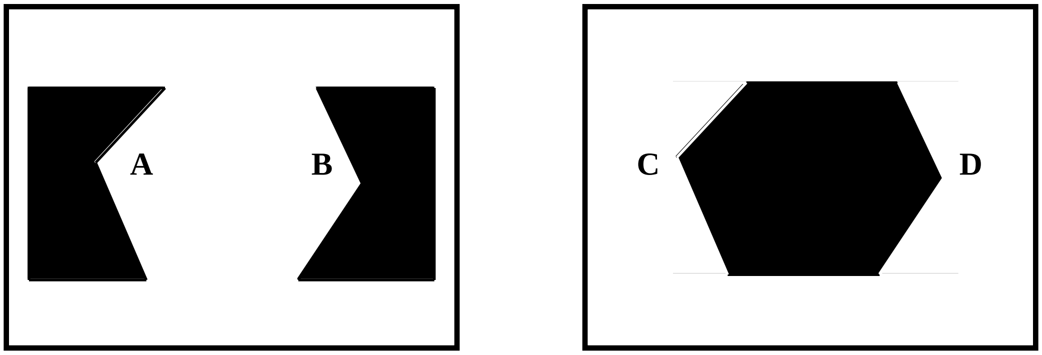


Figure Eight: It is easier to determine that vertex C is above D than to determine that A is above B (after Baylis & Driver, 1993).

Evidence that attention is directed to objects should not be read as evidence that attention cannot be directed to locations. Both types of deployment are possible. One line of evidence for this comes from studies of "inhibition of return" (Nakayama & Mackeben, 1989; Posner & Cohen, 1984). Once attention has been withdrawn it is harder to return attention to whatever was previously attended. A number of studies show that inhibition of return can be space-based or object-based (Gibson & Egeth, 1994; Tipper & Weaver, 1996; Tipper, Weaver, Jerreat & Burak, 1994) (see also Müller & von Muhlenen, 1996). For a theoretical treatment of this aspect of the data see Logan (1996).

Treisman and Kahneman introduced the idea "object files" that would be created through the agency of attention (Kahneman & Treisman, 1984; Kahneman, Treisman & Gibbs, 1992; Treisman, 1982). The evidence that attention is directed to objects suggests that some sort of object must exist preattentively. Wolfe and Bennett (1997) have called these "preattentive object files". When attention is directed to a preattentive object (or object file, if one prefers), the processing of the associated features of that object seems to have a mandatory flavor to it. Recent data show that all the features of an object enter memory as group (Luck & Vogel, 1997). Wolfe and Bennett (1997) found that the automatic attachment of features to objects can make apparently simple searches quite difficult. This is illustrated in Figure Nine.

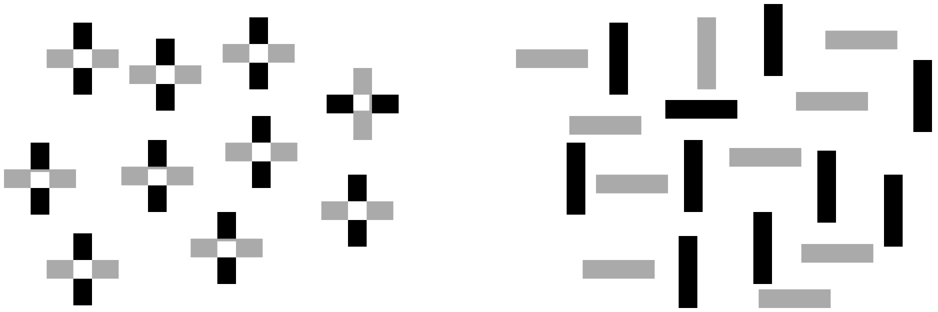


Figure Nine: You will probably find it easier to locate the black horizontal in the array on the right than in the array on the left (after Wolfe and Bennett, 1997).

Even though each array contains 10 gray lines and 10 black lines, it is easier to find the black horizontal line (or the gray vertical line) in the array on the right. On the right, each item is has a single color and a single orientation. On the left, the items are all “black” and “gray” and “vertical” and “horizontal”. Preattentive vision seems mandated to treat each “plus” as an object and seems unable to bind color to orientation in parallel.

2.5.1 Shape of entire objects

The work just reviewed shows that the preattentive world is parsed into some sort of objects prior to the arrival of attention. What do we know about the preattentive representation of the shape of whole objects?

When other features are controlled for, shape of an object does not appear to be available for the preattentive guidance of attention. Wolfe and Bennett (1997) performed a series of experiments with meaningful and meaningless stimuli and, in all cases, search for one shape among other shapes proved to be very inefficient. This does not mean that no aspect of shape is processed preattentively. For instance, grouping and good continuation make some sets of line segments into good, closed-curve objects while other sets do not form good objects (Figure Ten). Donnelly et al.(1991) showed that visual search is sensitive to the object-forming processes.

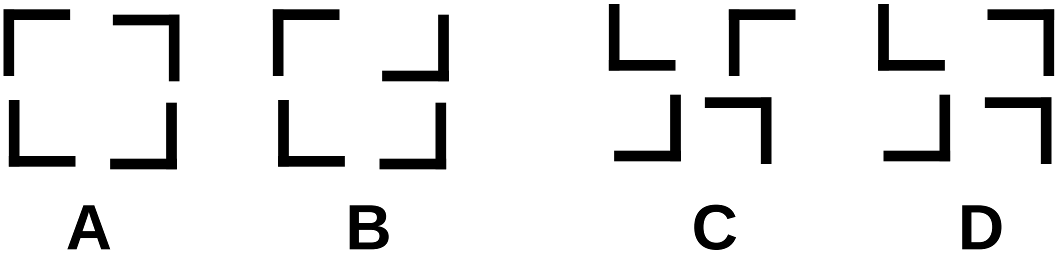


Figure Ten: It is much easier to tell A from B than C from D (after Donnelly et al., 1991). A forms an object. B forms a broken object. C and D are merely collections of Ls.

Looking at Figure Ten, searches for stimulus A among B are efficient because the 4 Ls group into a larger object. It may be that the identifying shape of an object is not available preattentively to guide attention. However, the basic processes of object formation are clearly occurring preattentively. Various other experiments could be used to make the same point including (Pomerantz & Pristach, 1989) and the work of Elder and Zucker, cited above.

2.5.2 Letters and Words

A great deal of work in the study of visual attention has used letters as stimuli. This produces a degree of confusion in the analysis of the visual aspects of visual attention because letters are not a simple set of stimuli. Letters can differ from each other in basic features like the orientation of their line segments (e.g. A vs H) or line termination (X vs O). Letters that do not differ in basic features (e.g. L vs T) must still be discriminable or they would be of little use as members of an alphabet. Are those letters preattentively disciminable and, if so, is that discriminability based on learned preattentive processing? There is evidence for efficient processing of letters (e.g. Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) but the visual properties of the letters were not a particular concern in this work. Wang and his colleagues (1994) argued for a preattentive distinction between overlearned letters and unlearned but related figures (like a mirror-reversed “N”) (see also Wang & Cavanagh, 1993). Their notion that novelty pops-out is related to similar claims on behalf of novel words by Johnston and his colleagues (Hawley, Johnston & Farnham, 1994; Johnston, Hawley & Farnham, 1993) (but see Christie & Klein, 1994).

There has been some suggestion that the categorical status of overlearned items like letters is available preattentively. For instance, some experiments seem to show that the character “0” is treated differently when it is thought of as an “oh” as opposed to “zero” (Brand, 1971; Egeth, Jonides & Wall, 1972). Subsequent work casts doubt on the robustness of this phenomenon (Duncan, 1983; Krueger, 1984).

Words and non-word letter strings behave differently as visual stimuli. However, with the exception of the novel pop-out claims of Johnston and his colleagues (Hawley et al., 1994; Johnston et al., 1993), the evidence suggests that these effects occur after attention has be directed to the stimulus (Bundesen, Kyllingsbaek, Houmann & Jensen, 1997; Flowers & Lohr, 1985; LaBerge, 1983)

2.5.3 Faces

Beyond basic features, there are two broad classes of complex stimuli that are repeatedly offered as candidates for preattentive processing. Letters and words were discussed above. The other class consists of faces and related stimuli. There is no doubt that search among upright faces is more efficient than search among inverted or scrambled faces (Suzuki & Cavanagh, 1995) (see also Levin, 1996; Reinitz, Morrissey & Demb, 1994) but these differences are differences between inefficient search for faces and *really* inefficient search through inverted or scrambled faces (Nothdurft, 1993d). Real or schematic faces behave the same way. A similar story holds for eye position. Von Grünau et al. (1995) found that search for a straight-ahead gaze was more efficient than search for gaze left or gaze right but this was a modulation of a basically inefficient search. Claims for efficient search for an angry face (Hansen & Hansen, 1988) have been challenged as artifactual (Purcell, Stewart & Skov, 1996).

2.6 Preattentive Summary

Evidence suggests that visual attention can be guided by the preattentive processing of a limited set of basic features. These include color, orientation, motion, size, curvature, various cues to depth, and several aspects of form (e.g. line termination). The case for preattentive processing of more complex properties like object shape, letters, or faces is weak though there is some evidence for efficient search for some overlearned stimuli. Conjunctions of features are implicitly available. For instance, color and orientation in the same place at the same time will produce an orientation contingent color aftereffect (the McCollough effect, Houck & Hoffman, 1986) (see also Mordkoff, Yantis & Egeth, 1990). However, those conjunctions do not seem to be explicitly available (see, for instance, Lavie, 1996).

3 Vision with attention

3.1 Attention enables other visual processes

If preattentive vision is a world of visual features loosely parsed into unidentified objects, then what is the role of attention when it arrives in that world? If we are going to attempt to encapsulate the role of attention in a single phrase, perhaps it would be best to say that attention serves as an *enabler* rather than an actor in its own right. Rather than saying that attention binds features, we would say that attention enables binding to occur. Rather than saying that attention somehow identifies an object, we would say that attention enables object recognition processes to work on a single item at a time. Indeed, attention enables a vast array of perceptual abilities. Consider that virtually all of vision research involves judgments about visual stimuli that are scrutinized with all available attention. Outside of those working on preattentive or inattentive vision, no one would design an experiment in which subjects were intended to make fine perceptual assessments of one stimulus while attending to another. This we may take as *prima facie* evidence that attention is required for many aspects of routine visual processing.

3.2 How and what does attention enable?

Attention enables visual processing in a wide variety of ways. The purpose of the next section is to catalog these various modes of attention. The items on this list should not be seen as mutually exclusive.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

SELECTION IN SPACE

Stimulus selection is one of the most critical functions of attention. There are many visual processes that simply cannot operate on the entire retinal image at once. Attention acts as a gatekeeper, passing a relevant subset of the stimuli to one or more limited capacity processes. Face perception is a clear example. As discussed above, face identification occurs one face at a time. The problem would seem to be that the face identifier wants to operate on one set of eyes, nose, mouth, etc. Presented with multiple faces, this limited-capacity process suffers from a version of the binding problem (e.g. Treisman, 1986). It does not know which eyes go with which nose, and so forth. Selective attention allows just one face to reach the face processor at one time.

In the 19th century, Helmholtz (1924) noted that one could selectively attend to stimuli away from the focus of attention. James (1890) put forth an early version of a spotlight metaphor in which attention acts like a mental flashlight, moving around the scene. The literature on the selective powers of attention is vast and this review can only point at some of its more salient features (for a much more extensive review see chapters 2 and 5 of Pashler, 1997) (see also Kahneman & Treisman, 1984; Lavie & Tsal, 1994a). Chapter 4 of Styles (1997) is devoted to the spotlight issue (see also Castiello & Umilta, 1992). As a metaphor for attentional selection, the spotlight needs substantial modification. First, there is the matter of the movement of the spotlight. If a real spotlight sweeps across a scene from point A to point B, it illuminates the space in between. When the spotlight of attention goes from A to B, this redeployment is probably better understood as attention withdrawing from one location and reappearing at another without necessarily illuminating intermediate locations - (e.g. Sagi & Julesz, 1985; Sperling and Weichselgartner, 1995) (but see Tsal, 1983). Second, a standard spotlight is directed to a location in space. The attentional spotlight is directed to objects. Space-based models, by themselves are inadequate to handle the data on objects (e.g. Schneider, 1993) though cueing of specific spatial locations can modulate the object-based effects (Lavie & Driver, 1996). Things get more complicated if a subject is asked to attend to items based on some feature (e.g. color). We found that subjects could process specific subsets of the stimuli in parallel in a visual search tasks even when the relevant and irrelevant items were intermixed (Friedman-Hill & Wolfe, 1995). As noted above, many others have found evidence for serial processing of subsets of stimuli (Egeth et al., 1984). This could be seen as evidence that attention can be directed to multiple locations at one time but perhaps this should be seen as a stage prior to the deployment of an attentional spotlight. Color (or some other basic feature) can be used to prioritize the subsequent deployment of attention. This is consistent with claims from several labs that selection by color is, in fact, selection of location based on color information (Cave & Pashler, 1995; Kim & Cave, 1995; Tsal & Lavie, 1993). Presumably, the same would hold for selection by other features.

Third, to the extent that attentional selection can be seen as a spotlight, its size is adjustable (Broadbent, 1982). A zoom lens has been offered as a metaphor (Eriksen & St.James, 1986) (c.f. Richards, 1968). This, in turn, leads to the idea that attention and processing capacity can be spread over multiple objects, maybe over the entire scene, and that attentional load is the critical determinant of the size of the spotlight (Lavie & Cox, 1996; Lavie & Tsal, 1994a, 1994b) (see also Nakayama, 1990).

Fourth, there is an ongoing debate about the ability to divide the spotlight into multiple, non-contiguous regions. It is probably the case that attention can select one object even if that object is broken into non-contiguous regions. For this point, the relevant experiments are those showing that attention can be attached to some group of items while apparently not spilling over on to intervening space or intervening items. For instance, Driver and Baylis (1989) showed more flanker interference (see below) with items that moved together, but see (Kramer, Tham & Yeh, 1991). Perhaps more striking are the experiments on multielement tracking (Intriligator et al., 1991; Pylyshyn & Storm, 1988; Yantis, 1992)(see also Culham & Cavanagh, 1994). In these studies, subjects are asked to attend to N out of M moving items. They can keep track of 3 to 6 of these. Pylyshyn's FINST theory accomplishes this by proposing that there is a preattentive, limited-capacity mechanism devoted to spatially indexing objects. These indexes allow attention to be efficiently guided to members of a desired subset of a set of moving objects as if they had blinking lights attached to them (Pylyshyn, 1989, 1994, 1998). Alternatively, attention might be used to hold 3-6 bits in some sort of virtual object (see Cavanagh's idea of attentional "sprites" - Cavanagh, 1997). In either case, as Driver and Baylis (1989) note, data of this sort make it clear that the spotlight metaphor cannot be taken in any literal sense. The spotlight of attention is doing things that no light source can do.

Fifth, control of selection is not perfect. One of the classic illustrations of this fact is the Eriksen flanker task (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973). In a flanker task, one might see three letters in a row. The instructions might be to push one key if the central letter was an "A" and another if it was a "B". The basic finding is that RTs for {A A A} are faster than for {C A C} which are, in turn, faster than {B A B}. The flanking letters, even though they are utterly irrelevant to the task, exert an influence on the response. They cannot be ignored. The effect varies with the spatial properties of the display (distance to the flankers, etc. Miller, 1991) and with load (Lavie's work, cited above).

Though this is not a review of the physiological literature on attention, it is worth mentioning that there are physiological correlates of selection by location/object (Moran & Desimone, 1985) and by feature (Motter, 1994a, 1994b). For a review, see Desimone & Duncan (1995).

SELECTION IN TIME

Attention is involved in the selection of items in time as well as in space. The "attentional blink" is an important example of this aspect of attention (Raymond, Shapiro & Arnell, 1992; Shapiro, 1994). In a standard attentional blink experiment, subjects monitor a stream of items appearing at a rate of around 10 Hz. Most often these would be alphanumeric characters, presented at fixation. Items can be monitored at this speed for the presence of a target element (Sperling, Budiansky, Spivak & Johnson, 1971); even for quite complex scene properties (Intraub, 1985; Potter, 1975, 1993; Potter & Levy, 1969). However, if subjects detect a first target, they will tend to be unable to respond to a second target presented within 200-500 msec of the first (e.g. Chun & Potter, 1995; Ward, Duncan & Shapiro, 1996, 1997). The fate of the "blinked" stimuli will be discussed when we talk about vision in the absence of attention (Section 5).

"Inhibition of return", mentioned above, is another example of attentional selection in time (Posner & Cohen, 1984). Attention to an object at one moment in time makes it harder to re-attend to the same object in the next second or so. Inhibition of return would seem like an obviously useful mechanism, preventing subjects from revisiting useless locations or objects during visual search tasks (Klein, 1988) but it has proven difficult to confirm a role for inhibition of return (Horowitz & Wolfe, 1997; Wolfe & Pokorny, 1990). See (Pratt & Abrams, 1995; Tipper, Weaver & Watson, 1996) for a similar controversy.

VIGILANCE

Faced with the impossibility of processing everything all of the time, attention enables resources to be devoted to important new events. Vigilance can be thought of as an attentional state in which a display is monitored for something worthy of focal attention. In typical vigilance tasks, subjects might be monitoring a display for the appearance of a designated target (e.g. Baker, 1958; Koelega, Brinkman, Hendriks & Verbaten, 1989). These tasks mimic important real-world tasks like the monitoring of air control displays or industrial equipment. For reviews see (Mackie, 1977; Parasuraman, 1986).

Vigilance implies an ability to spread some processing resource across a substantial portion of the visual field. It is possible to design tasks where vigilance in peripheral vision coexists with focal attention to some foveal tasks. This suggests that these are separate mechanisms of attention. Separate or not, focal attention does influence the ability to deploy resources to more peripheral locations. As a general rule, as foveal load increases, peripheral processing decreases in a form of attentional tunnel vision (Ikeda & Takeuchi, 1975; Williams, 1985, 1989). Rossi and Paradiso (1995) report an interesting wrinkle on this effect. The reduction of sensitivity to a peripheral grating depends on the relationship between the properties of that grating and the stimuli producing the central load.

Sanders(1970) talked about a “useful field of view”. Roughly speaking this is the region within which attention can be effectively deployed. In addition to shrinking as load increases, the useful field of view also shrinks as age increases (Ball, Beard, Roenker, Miller & Griggs, 1988; Owsley, Ball & Keeton, 1995; Sekuler & Ball, 1986). This effect is separable from any changes in perimetric visual field (Ball, Owsley & Beard, 1990) and may be related to real-world problems such as car accidents in the elderly (Ball, Owsley, Sloane, Roenker & Bruni, 1993) (see also Weltman & Egstrom, 1966).

There is also a bottom-up, stimulus driven aspect to attentional vigilance. Initially, it was proposed that abrupt onsets automatically attracted focal attention (Remington, Johnston & Yantis, 1992; Yantis & Johnson, 1990; Yantis & Jonides, 1990; see also Miller, 1989). Theeuwes (1991, 1994, 1995) argued for mandatory capture by onset stimuli, but this is probably too strong a claim (Bacon & Egeth, 1994; Wolfe, 1996). All else being equal, abrupt onsets will capture attention, but this can be modulated by top-down task demands.

More recently, Yantis and his colleagues have argued that it is not an onset *per se* that is critical. In a series of experiments, they have made a case for attentional deployment to new objects (Hillstrom & Yantis, 1994; Yantis, 1993; Yantis & Hillstrom, 1994). This seems reasonable. It would be useful to have a mechanism that automatically took note of new objects in the field. A mechanism that wanted to direct attention to any visual transient would be less useful since many uninteresting events in the world can produce such transients.

REDUCTION OF UNCERTAINTY

Consider the problem faced by some central decision-making process whose task it is to determine if a signal is present in a visual display. In the absence of any other information, that signal could be in any spatial location. Worse, if we do not know the nature of the signal, it could be found in any channel (Braddick et al., 1978). It could be low spatial frequency or red or moving or whatever. The decision maker is left in a state of great uncertainty. Attention enables uncertainty to be reduced. In most standard psychophysical experiments, the experimenter tells the subject where to look, when to look, and what to look for - all in an effort to reduce uncertainty. This implicit assumption about the role of attention has been explicitly tested several times (e.g. Davis, Kramer & Graham, 1983; Krupinski, Nodine & Kundel, 1993; Kurylo, Reeves & Scharf, 1996; Solomon, Lavie & Morgan, 1997). Inevitably, reduction of uncertainty makes tasks easier. This is often discussed in terms of signal detection theory (e.g. Swensson, 1980; Swensson & Judy, 1981).

These effects also serve to underline a point made earlier. Attention is not a term that is used to describe a single thing operating at a single locus. Reduction of uncertainty in space probably involves a different mechanism that reduction of uncertainty in a feature space or in time. Consider a search for a salient feature singleton. This is a very efficient search producing RT X set size slopes near zero. Nevertheless, RTs are shorter if the subject is certain about the feature space in which the singleton will appear (i.e. will it be an oddball in color or orientation or size?)(Müller, Heller & Ziegler, 1995; see also Bacon & Egeth, 1994)

ENHANCEMENT

Given that it is easier to detect or identify a stimulus when one is paying attention to that stimulus, several authors have wondered if attention acts to enhance the signal produced by that stimulus. There is evidence for such an enhancement at both the neural (Spitzer, Desimone & Moran, 1988) and the behavioral level (Sagi & Julesz, 1986; Urbach & Spitzer, 1995). In the context of signal detection theory, efforts have been made to separate detectability effects (d') from changes in response criterion. Evidence for changes in d' has been found (Downing, 1988; Hawkins et al., 1990). Sometimes both d' and criterion effects are found (e.g. Müller & Findlay, 1987). Sometime only criterion effects are seen (Palmer, Ames & Lindsey, 1993).

Many discriminations can be made only when attention is directed to a stimulus. As a general rule, preattentive processes such as those mediating "pop-out" require rather large differences between stimuli. Thus, in orientation, it is not possible to search efficiently for small orientation differences that can easily be discriminated with attention (Foster & Ward, 1991b; Wolfe et al., 1992a). Similar statements can be made about color (Nagy & Sanchez, 1990) or, indeed, about any basic feature.

There are two senses in which attention might enable fine perceptual discrimination. It could be that attention can be used to select small, preattentively generated signals. These signals might be present but unable to govern behavior without attention. Alternatively, attention might be required to sharpen or enhance the processing of a perceptual attribute. In this case, the signal would not exist prior to the application of attention.

SPEED OF PROCESSING

Some phenomena suggest that attention to an object or location actually speeds processing, even quite basic processing. For example, Shimojo and his colleagues flashed a horizontal line on a screen and asked subjects to say if the line appeared to be drawn from the left or the right end. An isolated line produces no systematic bias for either direction. However, if one end of the line is cued, in any of a variety of ways, that line will appear to be drawn from the cued end to the uncued end (Hikosaka, Miyauchi & Shimojo, 1993; Hikosaka, S. & S., 1996a; Hikosaka, Satoru, Hiroshige & Shinsuke, 1996b; Shimojo, Miyauchi & Hikosaka, 1992). They argued that the attended end of the line reaches awareness before the unattended end (see also Stelmach, Herdman & MacNeil, 1994). Some aspects of the effect may be better explained as versions of apparent motion (Downing & M., 1997; Tse, Cavanagh & Nakayama, 1998 Von Grünau, Dubé & Kwas, 1996; Von Grünau & Faubert, 1992). However, it does seem clear that the apparent motion of line can be modulated by attention.

MODULATION OF VISUAL PROCESSING

The line motion effects can be seen as evidence for the ability of attention to alter the perception of simple visual stimuli. Other evidence comes from studies of the attentional modulation of the effects of adaptation. Attention to the adapting stimuli is not a prerequisite for the production of aftereffects (He et al., 1996; Houck & Hoffman, 1986). However, attention does modulate aftereffects. For example, when two conflicting sources of adaptation are available, attention can select one and, thus, select the direction of adaptation (motion Lankheet & Verstraten, 1995) (Necker cube resolution Shulman, 1993b) (see also Chaudhuri, 1990; Shulman, 1991, 1993a). Attending away from the adapting stimulus reduces figural aftereffects (Shulman, 1992; Yeh, Ping, K. & L., 1996). Prism adaptation is also modulated by attention (Redding & Wallace, 1985). Physiological underpinnings of these effects may have been seen in single cells of macaques (Treue & Maunsell, 1996) and in human fMRI data (O'Craven, Rosen, Kwong & Treisman, 1997; Rees, Frith & Lavie, 1997).

FEATURE BINDING

Treisman has long argued that attention is needed to accurately bind features together (Treisman, 1986, 1988; Treisman & DeSchepper, 1996; Treisman & Gelade, 1980; Treisman & Sato, 1990). This is a central pillar of her important Feature Integration Theory (For some arguments with that pillar see Duncan & Humphreys, 1989, 1992; Navon, 1990a, 1990b; Treisman, 1990, 1991, 1992). In the first formulations of this idea, Treisman argued that features like color and orientation could float freely through the preattentive perceptual world. Illusory conjunctions, erroneously reported combinations of features, were one consequence of the failure to accurately bind features (Treisman & Schmidt, 1982). More recent formulations hold that features are at least roughly associated with locations and even with objects but that the relationship of features to their objects and to each other is not known in the absence of attention (see also Wolfe & Bennett, 1997). Thus, in Figure Eight, shown earlier, a preattentive object might have black, gray, vertical, and horizontal features; but only with attention would these features be bound into a "plus" composed of black vertical and gray horizontal bars.

Keele et al. (1988) asked if spatial or temporal synchrony was critical to binding and found that it was important that the features to be bound should occupy the same part of space.

Illusory conjunctions have generated an interesting body of research in their own right (e.g. Cohen & Ivry, 1989; Prinzmetal, Henderson & Ivry, 1995; Prinzmetal & Keysar, 1989). Some of this work indicates that illusory conjunctions are possible between attributes that are quite clearly not basic features (words Treisman & Souther, 1986), (scene elements Intraub, 1985),(elements of Chinese characters Fang & Wu, 1989). The meaning of the phenomenon remains controversial. In standard illusory conjunction paradigms, stimuli are briefly presented and the subject is queried about the appearance of those stimuli after they are gone. It is possible that the phenomenon shows that binding by attention is a fragile affair. As soon as the stimulus is gone, the explicit binding of the features ends and the possibility for error appears (Tsal, 1989a; Tsal, Meiran & Lavie, 1994) (but see Briand & Klein, 1989; Tsal, 1989b).

4. Vision after attention

Post-attentive vision, vision after attention, has been the subject of relatively little research to date. The visual percept of an object can be said to be preattentive before attention is directed to that object. The percept becomes attentive when attention is deployed to the object and post-attentive when attention departs that object for some other object. By this definition, much of a percept of a scene must become post-attentive over time. What is striking about the limited research on post-attentive vision is that there is little evidence for any difference between post-attentive and preattentive vision. That is, there is little evidence for persistent perceptual effects of attention.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

4.1 Repeated Search

We have use a “repeated search” task to examine post-attentive vision. In a standard visual search experiment, subjects might perform several hundred search trials. Each trial would involve a search through a different search display. In repeated search, subjects search multiple times through the same display as illustrated in Figure Ten.

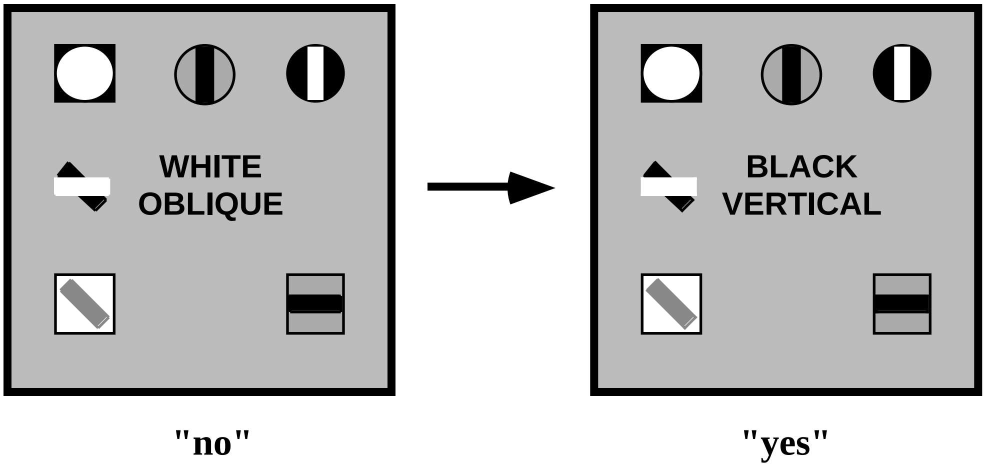


Figure Eleven: The Repeated Search Paradigm

On each trial, the designated target is indicated at the center of the display. In Figure Eleven, the subject is first asked if a "white oblique" is present in the display. It is not. On the next trial, only the probe at the center of the display changes to "black vertical". The search display remains unaltered and the answer is "yes". With stimuli of this sort, a standard visual search experiment would produce inefficient target -present slopes of about 40 msec/item. It is inefficient because the search set is very heterogeneous and, perhaps more importantly, because the target changes from trial to trial. In repeated search, even though subjects are searching the same display over and over, search does not become more efficient (Wolfe, Klempen & Dahlen, 1998). This failure to improve search efficiency holds over a wide range of variations on the repeated search theme. We have used letters, real objects, arbitrary closed curves, in addition to these compound conjunction stimuli. We have had subjects search hundreds of times through the same few stimuli. If a search was inefficient on trial 1, it remains inefficient on trial N.

This is not to say that attention has no consequences. For instance, after multiple searches through the same set of letters, subjects certainly remember the letters. Subjects know more about attended stimuli. However, they do not seem to see more of those stimuli. In most real world tasks, the encoding of a scene into memory would be useful ("Didn't I leave those keys by the back door?"). However, in our repeated search tasks, the best a subject could do with memory would be to replace a visual search through N items with a memory search through N items. Such a search would proceed at a rate equivalent to about 40 msec/item (McElree & Dosher, 1989; Sternberg, 1969) - no better than the inefficient visual search.

4.2 Change Blindness

The lack of lasting perceptual consequences of attention is dramatically illustrated by a phenomenon that Rensink (1996b) has dubbed "change blindness". (Simons & Levin, 1997a). Change blindness is illustrated in Figure Twelve. You may find that it takes a surprisingly long time to notice the difference between the two images.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Figure Twelve: Change Blindness:

What is the difference between the two images?

This is not a true example of change blindness because there are actually two images in two different places (Blackmore, Brelstaff, Nelson & Troscianko, 1995). However, subjects are just as blind to changes in a single scene as long as the change is made in a manner that does not produce an attention-grabbing visual transient. (Look at the

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

cook if you still have not found the change in Figure Eleven.) Thus, subjects fail to notice substantial changes made during saccades (Grimes, 1996) (see also Irwin, 1996; Irwin, Zacks & Brown, 1989, 1990). Movie makers know that it is hard to detect changes when the camera moves away from a scene and then returns (Levin & Simons, 1997; Simons, 1996). They also miss changes between two versions of a scene if a blank screen is briefly presented between scenes to mask the transients (Pashler, 1988; Rensink, O'Regan & Clark, 1995, 1996a) or if a salient transient is added to the scene to distract attention from the transient caused by the change (O'Regan, Rensink & Clark, 1996). Finally, we cannot leave the topic of change blindness without mentioning the experiment of Simons and Levin (1997b). They engaged pedestrians in conversation and changed the identity of the experimenter/conversationalist during the conversation. To mask the change, they had two "workers" carry a door between the subject and experimenter. Under these conditions, fifty percent of subjects failed to notice the change to a new person.

The change blindness demonstrations are interesting because, in many cases, there is no question that observers have attended to the scene and to the objects in the scene. Nevertheless, substantial changes in the scene are missed. The changes are seen when the observer's attention remains with an object while it changes. Prior attention to the object is usually not enough, suggesting that the post-attentive visual representation is quite sketchy (For further discussion of these issues see Wolfe, 1997a; Wolfe et al., 1998).

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

5. Vision without attention

5.1 The Problem

Finally, we should say something about the fate of visual stimuli that are never attended. As a general rule, studies of the effects of inattention try to force subjects to attend to one stimulus while other stimuli are presented. The subject is then queried, implicitly or explicitly, about the unattended stimulus. Experiments of this sort yield a very wide range of opinions about the fate of the unattended. At one extreme, Mack and her colleagues have argued for "inattentional blindness" (Mack & Rock, 1996; Mack, Tang, Tuma & Kahn, 1992). At the other extreme are claims for semantic processing of unattended words (Hawley et al., 1994; Johnston et al., 1993). These debates about unattended stimuli are the latest version of the late vs early selection debates in the attention literature (well reviewed by Pashler, 1997). Models that hold that preattentive processing stops with the processing of basic features can be labeled as "early selection models". Models that hold that stimuli are much more thoroughly processed preattentively are late selection models. In early selection models, attention is needed to complete the act of perception. In late selection models, attention selects responses to fully processed stimuli.

5.2 How unattended can you get?

Can any sense be made out of the divergent studies of the perception of unattended stimuli? While the topic remains controversial, some headway can be made. First, we should consider what it means for a stimulus to be unattended. In a series of experiments, Braun and his colleagues had subjects perform a demanding visual search task at fixation and, at the same time, assessed their ability to perform other search tasks in the periphery. Simple visual search tasks for feature singletons like color and shape from shading were still possible (Braun, 1993; Braun & Julesz, 1996; Braun & Sagi, 1990, 1991). Other tasks like grouping were impaired (Ben-Av, Sagi & Braun, 1992). This would seem to support a view that basic features are available in unattended stimuli but that more complicated properties are not. However, Joseph, Chun, and Nakayama (1997) did a rather similar experiment but tied up attention with the attentional blink (see Section 3.2). Now even a simple orientation pop-out task became impossible. It is possible that the Joseph et al. (1997) method ties up attention more completely than Braun's task. Lavie's work has shown that the fate of stimuli that are irrelevant to a task depends on the attentional load imposed by the relevant stimuli (Lavie, 1995; Lavie & Cox, 1996; Lavie & Tsal, 1994a).

It may be too simple to suggest that the attentional blink is a particularly effective way to capture attention. Consider, for example, that implicit measures show that subjects can extract meaning from words presented during an attentional blink (Luck, Vogel & Shapiro, 1996; Shapiro, Driver, Ward & Sorenson, 1997). Research on negative priming may help explain how it can be possible to read during a blink and still be unable to perform a simple search task. In a standard negative priming experiment, subjects are presented with two, partially overlapping stimuli. They are instructed to ignore one stimulus and make some report about the other. If the ignored stimulus is presented on the next trial as the to-be-attended stimulus, then subjects are somewhat slowed in their responses as compared to their responses to a neutral stimulus (Tipper, 1985; Tipper & Cranston, 1985; Tipper & Driver, 1988; Tipper & Weaver, 1996). It seems that the "unattended" stimulus was quite fully processed and had to be actively inhibited in order to be successfully ignored. Even novel objects can be inhibited (DeSchepper & Treisman, 1996) suggesting that the ignored object is coded into memory without being explicitly attended.

5.3 All inattention is not created equal.

These negative priming effects fail to occur when multiple items are ignored (Neumann & DeSchepper, 1992). That is, if you are instructed to respond to a red "A" and ignore a green

"B", it will be possible to measure inhibition with a subsequently presented "B". However, if the irrelevant set is larger, B C D E, inhibition will not be seen. This strongly suggests that "ignored" is not quite the same as "unattended". With only a couple of stimuli, it may be impossible not to devote some processing resources to the irrelevant stimulus (again, see Lavie, 1995). The irrelevant stimulus is inhibited in order to keep it from interfering with the task at hand. With multiple stimuli, attention simply never reaches most of the irrelevant items. Evidence suggests that there is processing of the basic features of these items (e.g. Houck & Hoffman, 1986) but not of more complex properties (like letter identity Eriksen, Webb & Fournier, 1990).

We run into definitional problems in the case of the "ignored" stimuli. They share some attributes with attentionally blinked stimuli and with stimuli lost to inattentional blindness. They cannot be explicitly reported. For instance, in the case of negative priming of novel shapes, there is no explicit recognition of the shapes (DeSchepper & Treisman, 1996). However, as already discussed, there is substantial implicit evidence for quite high level processing of these stimuli. One possibility, put forth by Wolfe (1997a) is that these stimuli are seen but are removed without they being coded into explicit memory. Thus, subjects would be amnesic for these stimuli. Like any good amnesic, subjects would deny seeing the stimuli if queried after the stimuli were removed. It becomes a semantic point whether one wants to label such stimuli as "attended" or "unattended". The important point, for present purposes, is that stimuli can be divided into three broad categories. There are explicitly attended stimuli. These can be recognized and acted upon. There are stimuli that attention never reaches. These seem to leave marks of their preattentive features but probably not of their more complex properties. Finally, there are stimuli that receive some processing resources but fail to leave any lasting impression on the observer. These may be seen but instantly forgotten leaving implicit but not explicit traces for the experimenter to measure.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

6 Conclusion

From the vantage point of vision research, the study of attention is rather sobering. The evidence suggests that focal attention can be directed to one or, perhaps, a few objects at any one time. The number of possible targets for attention in a visual scene is usually many times that number. Consequently, most of the visual stimuli that we see at any moment are represented either preattentively or postattentively. Most of what we know about vision, on the other hand, comes from studies in which the stimulus is the focus of attention. We have a detailed description of only a small part of visual experience. This is not meant as a criticism of vision research. If one was going to concentrate on any aspect of vision, the processing of attended stimuli would be a sensible place to focus one's energy. After all, most if not all of the visual control of behavior requires attention. In Patrick Cavanagh's felicitous phrase, attention is in the business of "exporting vision to the mind" (Cavanagh, 1997).

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

REFERENCES

Aks, D. J., & Enns, J. T. (1992). Visual search for direction of shading is influenced by apparent depth. Perception and Psychophysics, 52(1), 63-74.

Alkhateeb, W. F., Morland, A. B., Ruddock, K. H., & Savage, C. J. (1990a). Spatial, colour, and contrast response characteristics of mechanisms which mediate discrimination of pattern orientation and magnification. Spatial Vision, 5(2), 143-157.

Alkhateeb, W. F., Morris, R. J., & Ruddock, K. H. (1990b). Effects of stimulus complexity on simple spatial discriminations. Spatial Vision, 5(2), 129-141.

Andersen, G. J. (1990). Focused attention in three-dimensional space. Perception & Psychophysics, 47, 112-120.

Backs, R. W., & Walrath, L. C. (1995). Ocular measures of redundancy gain during visual search of colour symbolic displays. Ergonomics, 38(9), 1831-1840.

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. Perception and Psychophysics, 55(5), 485-496.

Baker, C. H. (1958). Attention to visual displays during a vigilance task: I. Biasing attention. British Journal of Psychology, 49, 279-288.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes among older drivers. Investigative Ophthalmology and Visual Science, 34(11), 3110-3123.

Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: expanding the useful field of view. J. Optical Society of America - A, 5(12), 2210-2219.

Ball, K. K., Owsley, C., & Beard, B. (1990). Clinical visual field perimetry underestimates visual field problems in older adults. Clinical Vision Science, 5(2), 113-125.

Bauer, B., Jolicœur, P., & Cowan, W. B. (1996a). Visual search for colour targets that are or are not linearly-separable from distractors. Vision Research, 36(10), 1439-1466.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Bauer, B., Pierre, J., & B., C. W. (1996b). Distractor heterogeneity versus linear separability in colour visual search. Perception, 25(1), 1281-1294.

Baylis, G. C. (1994). Visual attention and objects: Two object cost with equal convexity. J. Experimental Psychology: Human Perception and Performance, 20(1), 208-212.

Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. J. Exp. Psychol. - Human Perception and Performance, 19(3), 451-470.

Beck, J. (1966a). Effect of orientation and shape similarity on perceptual grouping. Perception and Psychophysics, 1, 300-302.

Beck, J. (1966b). Perceptual grouping produced by changes in orientation and shape. Science, 154, 538-540.

Beck, J. (1982). Textural segmentation. In J. Beck (Ed.), Organization and representation in perception., . Hillsdale, NJ: Erlbaum.

Ben-Av, M. B., Sagi, D., & Braun, J. (1992). Visual attention and perceptual grouping. Perception and Psychophysics, 52(3), 277-294.

Berbaum, K., Chung, C., & Loke, W. (1986). Improved localization of moving targets with prior knowledge of direction of target motion. Am. J. Psychology, 99(4), 509-514.

Bergen, J. R., & Adelson, E. H. (1988). Early vision and texture perception. Nature, 333, 363-364.

Bergen, J. R., & Julesz, B. (1983). Rapid discrimination of visual patterns. IEEE Trans on Systems, Man, and Cybernetics, SMC-13, 857-863.

Berger, R. C., & McLeod, P. (1996). Display density influences visual search for conjunctions of movement and orientation. J. Experimental Psychology: Human Perception and Performance, 2(1), 114-121.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Bilsky, A. A., & Wolfe, J. M. (1995). Part-whole information is useful in size X size but not in orientation X orientation conjunction searches. Perception and Psychophysics, 57(6), 749-760.

Bilsky, A. A., Wolfe, J. M., & Friedman-Hill, S. F. (1994). Part-whole information is useful in size X size but not in orientation X orientation conjunction searches. Investigative Opthalmology and Visual Science., 35(4), 1622.

Blackmore, S. J., Brelstaff, G., Nelson, K., & Troscianko, T. (1995). Is the richness of our visual world an illusion? Transsaccadic memory for complex scenes. Perception, 24, 1075-1081.

Blake, R. (1989). A neural theory of binocular rivalry. Psych. Review, 96, 145-167.

Blakemore, C., & Over, R. (1974). Curvature detectors in human vision. Perception, 3, 3-7.

Braddick, O., Campbell, F. W., Atkinson, J., Held, R., Leibowitz, W. H., & Teuber, H.-L. (1978). Channels in vision: Basic aspects, Perception: Handbook of Sensory Physiology, (pp. 3-38). Berlin: Springer-Verlag.

Braddick, O. J., & Holliday, I. E. (1991). Serial search for targets defined by divergence or deformation of optic flow. Perception, 20(3), 345-354.

Brand, J. (1971). Classification without identification in visual search. Quarterly Journal of Experimental Psychology, 23, 178-186.

Braun, J. (1993). Shape-from-shading is independent of visual attention and may be a texton. Spatial Vision, 7(4), 311-322.

Braun, J., & Julesz, B. (1996). Dividing attention at little cost: detection and discrimination tasks. Perception and Psychophysics, in press.

Braun, J., & Sagi, D. (1990). Vision outside the focus of attention. Perception & Psychophysics, 48(1), 45-58.

Braun, J., & Sagi, D. (1991). Texture-based tasks are little affected by second tasks requiring peripheral or central attentive fixation. Perception, 20, 483-500.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Bravo, M., & Blake, R. (1990). Preattentive vision and perceptual groups. Perception, 19, 515-522.

Bravo, M. J., & Blake, R. (1992). The contributions of figure and ground textures to segmentation. Vision Research, 32(9), 1793-1800.

Briand, K. A., & Klein, R. M. (1989). Has feature integration come unglued? A reply to Tsal. J. Exp. Psychol. - Human Perception and Performance, 15(2), 401-406.

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

Bundesen, C. (1996). Formal models of visual attention: A tutorial review. In A. Kramer, G. H. Cole, & G. D. Logan (Eds.), Converging operations in the study of visual selective attention., (pp. 1-44). Washington, DC: American Psychological Association.

Bundesen, C., Kyllingsbaek, S., Houmann, K. J., & Jensen, R. M. (1997). Is visual attention automatically attracted by one's own name? Perception and Psychophysics, 59(5), 714-720.

Bundesen, C., & Pedersen, L. F. (1983). Color segregation and visual search. Perception and Psychophysics, 33, 487-493.

Caelli, T., Julesz, B., & Gilbert, E. (1978). On perceptual analyzers underlying texture discrimination. Biological Cybernetics, 29, 201-214.

Caerwinski, M., Lightfoot, N., & Shiffrin, R. (1992). Automatization and training in visual search. American Journal of Psychology, 105(2), 271-315.

Carrasco, M., Evert, D. L., Chang, I., & Katz, S. M. (1995). The eccentricity effect: Target eccentricity affects performance on conjunction searches. Perception and Psychophysics, 57(8), 1241-1261.

Carrasco, M., & Frieder, K. S. (1997). Cortical mgnification neutralizes the eccentricity effect in visual search. Vision Research, 37(1), 63-82.

Carter, R. C. (1982). Visual search with color. . J. Experimental Psychology: Human Perception and Performance, 8(1), 127- 136.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Castiello, U., & Umilta, C. (1992). Splitting focal attention. J. Experimental Psychology: Human Peception and Performance., 18(3), 837-848.

Cavanagh, P. (1997). Attention: Exporting vision to the mind. In C. Taddei-Ferretti (Ed.), Neuronal basis and psychological aspects of consciousness., (pp. in press). Singapore: World Scientific.

Cavanagh, P., Arguin, M., & Treisman, A. (1990). Effect of surface medium on visual search for orientation and size features. J. Experimental Psychology: Human Perception and Performance, 16(3), 479-492.

Cavanagh, P., & Mather, G. (1989). Motion: The long and the short of it. Spatial Vision, 4, 103-129.

Cave, K. R., & Pashler, H. (1995). Visual selection mediated by location: Selecting successive visual objects. Perception & Psychophysics, 57(4), 421-432.

Chau, A. W., & Yei-Yu, Y. (1995). Segregation by color and stereoscopic depth in three-dimensional visual space. Perception & Psychophysics, 57(7), 1032-1044.

Chaudhuri, A. (1990). Modulation of the motion aftereffect by selective attention. Nature, 344(6261), 60-62.

Cheal, M., & Lyon, D. (1992). Attention in visual search: Multiple search classes. Perception and Psychophysics, 52(2), 113-138.

Chen, L. (1982). Toplogical structure in visual perception. Science, 218, 699-700.

Chen, L. (1990). Holes and wholes: A reply to Rubin and Kanwisher. Perception and Psychophysics, 47, 47-53.

Chen, L., & Zhou, W. (1995). Holes in illusory conjunctions. Psychonomic Bulletin and Review, ms 95-85 reviewed 7/95.

Christie, J., & Klein, R. (1994). Novel popout: The true story. Presented at the 35th annual meeting of the Psychonomic Society, November, 1994, St. Louis, MO.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in RSVP. Journal of Experimental Psychology : Human Perception & Performance, 21(1), 109-127.

Chun, M. M., & Wolfe, J. M. (1996). Just say no: How are visual searches terminated when there is no target present? Cognitive Psychology, 30, 39-78.

Cohen, A., & Ivry, R. B. (1989). Illusory conjunction inside and outside the focus of attention. J. Exp. Psychol. Human Perception and Performance, 15, 650-663.

Cohen, A., & Ivry, R. B. (1991). Density effects in conjunction search: Evidence for coarse location mechanism of feature integration. J. Exp. Psychol. Human Perception and Performance, 17(4), 891-901.

Culham, J. C., & Cavanagh, P. (1994). Motion capture of luminance stimuli by equiluminous color gratings and by attentive tracking. Vision Research, 34(20), 2701-2706.

D'Zmura, M., & Lennie, P. (1988). Attentional selection of chromatic mechanisms. Invest. Ophthalmol. Vis. Sci. (suppl), 29, 162.

D'Zmura, M., & Mangalick, A. (1993). Detection of contrary chromatic change. Journal of the Optical Society of America A, 11(2), 543-546.

Davis, E., Kramer, P., & Graham, N. (1983). Uncertainty about spatial frequency, spatial position, or contrast of visual patterns. Perception and Psychophysics, 33, 20-28.

Dehaene, S. (1989). Discriminability and dimensionality effcts in visual search for featural conjunctions: a functional pop-out. Perception & Psychophysics, 46(1), 72-80.

DeSchepper, B., & Treisman, A. (1996). Visual memory of novel shapes: Implicit coding without attention. J. Experimental Psychology: Learning, Memory & Cognition, 22(27-47).

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. Annual Review Neuroscience, 18, 193-222.

Dick, M., Ullman, S., & Sagi, D. (1987). Parallel and serial processes in motion detection. Science, 237, p400-402.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Donk, M., & Meinecke, C. (1997, Nov, 1997). The effects of retinal eccentricity in texture segmentation and element search. Paper presented at the Annual Meeting of the Psychonomic Society, Philadephia.

Donnelly, N., Humphreys, G. W., & Riddoch, M. J. (1991). Parallel computation of primitive shape descriptions. Journal of Experimental Psychology: Human Perception & Performance, 17(2), 561-570.

Downing, C. J. (1988). Expectancy and visual-spatial attention: Effects on perceptual quality. J. Exp. Psychol., 14, 188-202.

Downing, C. J., & Pinker, S. (1985). The spatial structure of visual attention. In M. I. Posner & O. S. M. Marin (Eds.), Mechanisms of attention: Attention and performance XI, (pp. 171-187). NY: Hillsdale.

Downing, P. E., & Treisman, A. M. (1997). The line-motion illusion: Attention or impletion? Journal of Experimental Psychology: Human Perception & Performance, 23(3), 768-779.

Driver, J., & Baylis, G. C. (1989). Movement and visual attention: The spotlight metaphor breaks down. J. Exp. Psychol - Human Perception and Performance, 15(3), 448-456.

Driver, J., & McLeod, P. (1992). Reversing visual search asymmetries with conjunctions of movement and orientation. J. Experimental Psychology: Human Perception and Performance, 18, 22-33.

Driver, J., McLeod, P., & Dienes, Z. (1992a). Are direction and speed coded independently by the visual system? Evidence from visual search. Spatial Vision, 6(2), 133-147.

Driver, J., McLeod, P., & Dienes, Z. (1992b). Motion coherence and conjunction search: Implications for guided search theory. Perception and Psychophysics, 51(1), 79-85.

Duncan, J. (1983). Category effects in visual search: A failure to replicate the "oh-zero" phenomenon. Perception and Psychophysics, 34(3), 221-232.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Duncan, J. (1984). Selective attention and the organization of visual information. J. Exp. Psychol. Gen., 113, 501-517.

Duncan, J. (1988). Boundary conditions on parallel processing in human vision. . Perception, 17, 358.

Duncan, J. (1993). Coordination of what and where systems in the visual control of behaviour. Perception, 22, 1261-1270.

Duncan, J. (1995). Target and non-target grouping in visual search. Perception and Psychophysics, 57(1), 117-120.

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

Duncan, J., & Humphreys, G. W. (1992). Beyond the search surface: Visual search and attentional engagement. J. Exp. Psychol: Human Perception and Performance, 18(2), 578-588.

Durgin, F. H., & Wolfe, S. E. (1997). Global precedence in visual search? Not so fast: Evidence instead for an oblique effect. Peception, 26, 321-332.

Eckstein, M. P., Thomas, J. P., Palmer, J., & Shimozaki, S. S. (1996). Further predictions of signal detection theory on visual search accuracy: Conjunctions, disjunctions, and triple conjunctions. Investigative Ophthalmology and Visual Science, 37(3), S15.

Efron, R., & Yund, E. W. (1996). Spatial uniformities in visual search. Brain & Cognition, 31(3), 331-368.

Egeth, H., Jonides, J., & Wall, S. (1972). Parallel processing of multielement displays. Cognitive Psychology, 3, 674-698.

Egeth, H. E., Virzi, R. A., & Garbart, H. (1984). Searching for conjunctively defined targets. J. Exp. Psychol: Human Perception and Performance, 10, 32-39.

Egeth, H. E., & Yantis, S. (1998). Visual Attention: Control, representation, and time course. Annual Review of Psychology, 48, in press.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Elder, J., & Zucker, S. (1993). The effect of contour closure on the rapid discrimination of two-dimensional shapes. Vision Research, 33(7), 981-991.

Elder, J., & Zucker, S. (1994). A measure of closure. Vision Research, 34(24), 3361-3369.

Elder, J., & Zucker, S. (1998). Evidence for boundary-specific grouping. Vision Research, 38(1), 142-152.

Enns, J. (1986). Seeing textons in context. Perception and Psychophysics, 39(2), 143-147.

Enns, J. T. (1992). Sensitivity of early human vision to 3-D orientation in line-drawings. Canadian J of Psychology, 46(2), 143-169.

Enns, J. T., & Kingstone, A. (1995). Access to global and local properties in visual search for compound stimuli. Psychological Science, 6(5), 283-291.

Enns, J. T., & Rensink, R. A. (1990a). Scene based properties influence visual search. Science, 247, 721-723.

Enns, J. T., & Rensink, R. A. (1990b). Sensitivity to three-dimensional orientation in visual search. Psychological Science, 1(5), 323-326.

Enns, J. T., & Rensink, R. A. (1991). Preattentive recovery of three-dimensional orientation from line drawings. Psych. Review, 98(3), 335-351.

Enns, J. T., & Rensink, R. A. (1993). A model for the rapid discrimination of line drawing in early vision. In D. Brogan, A. Gale, & K. Carr (Eds.), Visual Search 2, (pp. 73-89). London, UK: Taylor & Francis.

Epstein, W., & Babler, T. (1990). In search of depth. Perception and Psychophysics, 48(1), 68-76.

Epstein, W., Babler, T., & Bownds, S. (1992). Attentional demands of processing shape in three-dimensional space: Evidence from visual search and precuing paradigms. J. Experimental Psychology: Human Perception and Performance, 18(2), 503-511.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. Perception & Psychophysics., 16, 143-149.

Eriksen, C. W., & Hoffman, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. Perception & Psychophysics, 14, 155-160.

Eriksen, C. W., & St.James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. Perception and Psychophysics, 40, 225-240.

Eriksen, C. W., Webb, J. M., & Fournier, L. R. (1990). How much processing do nonattended stimuli receive? Apparently very little, but . . . Perception & Psychophysics, 47(5), 477-488.

Fahle, M. (1991). A new elementary feature of vision. Invest. Ophthalmol. Vis. Sci., 32(7), 2151-2155.

Fahle, M. W. (1990). Parallel, semi-parallel, and serial processing of visual hyperacuity. Paper presented at the SPIE: Human Vision and Electronic Imaging: Models, Methods, and Applications, Santa Clara, CA.

Fang, S.P., & Wu, P. (1989). Illusory conjunctions in the perception of Chinese characters. J. Exp. Psychol - Human Perception and Performance, 15(3), 434-447.

Farell, B., & Pelli, D. G. (1993). Can we attend to large and small at the same time? Vision Research, 33(18), 2757-2772.

Farmer, E. W., & Taylor, R. M. (1980). Visual search through color displays: Effects of target-background similarity and background uniformity. Perception and Psychophysics, 27, 267-272.

Findlay, J. M. (1995). Visual search: eye movements and peripheral vision. Optometry and Vision Science, 72, 461-466.

Flowers, J. H., & Lohr, D. J. (1985). How does familiarity affect visual search for letter strings? Perception and Psychophysics, 37, 557-567.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Foster, D. H. (1983). Visual discrimination, categorical identification, and categorical rating in brief displays of curved lines: implications for discrete encoding processes. Journal of Experimental Psychology: Human Perception and Performance, 9(5), 785-806.

Foster, D. H., & Ward, P. A. (1991a). Asymmetries in oriented-line detection indicate two orthogonal filters in early vision. Proceedings of the Royal Society (London B), 243, 75-81.

Foster, D. H., & Ward, P. A. (1991b). Horizontal-vertical filters in early vision predict anomalous line-orientation frequencies. Proceedings of the Royal Society (London B), 243, 83-86.

Foster, D. H., & Westland, S. (1993). Orientation fine-structure in line-target detection. In A. Gale, Carr, K (Ed.), Visual Search III, (pp. MS): Taylor & Francis.

Foster, D. H., & Westland, S. (1995). Orientation contrast vs orientation in line-target detection. Vision Research, 35(6), 733-738.

Friedman-Hill, S. R., & Wolfe, J. M. (1995). Second-order parallel processing: Visual search for the odd item in a subset. J. Experimental Psychology: Human Perception and Performance, 21(3), 531-551.

Garner, W. R., Hake, H. W., & Eriksen, C. W. (1956). Operationism and the concept of perception. Psychological Review, 63, 149-159.

Gibson, B. S. (1994). Visual attention and objects: One vs two or convex vs concave? J. Experimental Psychology: Human Perception and Performance, 20(1), 203-207.

Gibson, B. S., & Egeth, H. (1994). Inhibition of return to object-based and environment-based locations. Perception and Psychophysics, 55(3), 323-339.

Gilchrist, I. D., W., H. G., Jane, R. M., & Heiko, N. (1997). Luminance and edge information in grouping: A study using visual search. Journal of Experimental Psychology: Human Perception & Performance, 23(2), 464-480.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Grabowecky, M., & Khurana, B. (1990). Features were meant to be integrated. Investigative Ophthalmology and Vision Science, 31(4), 105.

Graham, N., Venkatesan, C., & Sutter, A. (1993). Spatial-frequency- and orientation-selectivity of simple and complex channels in region segregation. Vision Research, 33(14), 1893-1911.

Green, B. F., & Anderson, L. K. (1956). Color coding in a visual search task. J. Exp. Psychol., 51, 19-24.

Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. Akins (Ed.), Perception, (pp. 89-110). New York: Oxford University Press.

Gurnsey, R., & Browse, R. A. (1989). Asymmetries in visual texture discrimination. Spatial Vision, 4(1), 31-44.

Hansen, C. H., & Hansen, R. D. (1988). Finding the face in the crowd: An anger superiority effect. Journal of Personality & Social Psychology, 54(6), 917-924.

Hawkins, H. L., Hillyard, S. A., Luck, S. J., Mouloua, M., Downing, C. J., & Woodward, D. P. (1990). Visual attention modulates signal detectability. J. Exp. Psychol: Human Perception and Performance, 16(4), 802-811.

Hawley, K. J., Johnston, W. A., & Farnham, J. M. (1994). Novel popout with nonsense string: Effects of predictability of string length and spatial location. Perception and Psychophysics, 55, 261-268.

He, J. J., & Nakayama, K. (1994a). Perceived surface shape not features determines correspondence strength in apparent motion. Vision Research, 34(16), 2125-2135.

He, J. J., & Nakayama, K. (1994b). Perceiving textures: Beyond filtering. Vision Research, 34(2), 151-162.

He, S., Cavanagh, P., & Intriligator, J. (1996). Attentional resolution and the locus of visual awareness. Nature, 383(26 Sept 1996), 334-337.

He, Z. J., & Nakayama, K. (1992). Surfaces versus features in visual search. Nature, 359, 231-233.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Heathcote, A., & Mewhort, D. J. K. (1993). Representation and selection of relative position. J. Exp. Psychol. - Human Perception and Performance, 19(3), 488-516.

Helmholtz, H. v. (1924). Treatise on Physiological Optics (Southall, Trans.). (Trans. from 3rd German ed. of 1909, ed.): The Optical Society of America.

Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993). Focal visual attention produces illusory temporal order and motion sensation. Vision Research, 33(9), 1219-1240.

Hikosaka, O., Miyauchi, S., Takeichi, H., & Shimojo, S. (1996). Multimodal spatial attention visualized by motion illusion. In T. Inui & J. L. McClelland (Eds.), Attention and performance 16: Information integration in perception and communication. Attention and performance., (Vol. 16, pp. 237-261). Hillsdale, NJ: L. Erlbaum. Hikosaka, O., Satoru, M., Hiroshige, T., & Shinsuke, S. (1996b). Multimodal spatial attention visualized by motion illusion. In T. Inui & J. L. McClelland (Eds.), Attention and performance 16: Information integration in perception and communication. Attention and performance., (Vol. 16, pp. 237-261). Hillsdale, NJ: L. Erlbaum.

Hillstrom, A. P., & Yantis, S. (1994). Visual motion and attentional capture. Perception & Psychophysics, 55, 399-411.

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

Holliday, I. E., & Braddick, O. J. (1991). Pre-attentive detection of a target defined by stereoscopic slant. Perception, 20, 355-362.

Horowitz, T., & Treisman, A. (1994). Attention and apparent motion. Spatial Vision, 8(2), 193-219.

Horowitz, T. S., & Wolfe, J. M. (1997). Is visual search lost in space? Investigative Ophthalmology and Visual Science, 38(4), S688.

Houck, M. R., & Hoffman, J. E. (1986). Conjunction of color and form without attention. Evidence from an orientation-contingent color aftereffect. JEP: HPP, 12, 186-199.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Hübner, R. (1993). On possible models of attention in signal detection. Journal of Mathematical Psychology, 37(2), 266-281.

Ikeda, M., & Takeuchi, T. (1975). Influence of foveal load on the functional visual field. Perception and Psychophysics, 18, 255-260.

Intraub, H. (1985). Visual dissociation: An illusory conjunction of pictures and forms. J. Experimental Psychology: Human Perception and Performance., 11, p431-442.

Intriligator, J., Nakayama, K., & Cavanagh, P. (1991). Attention tracking of multiple moving objects at different scales. Investigative Ophthalmology and Visual Science, 32(4), S1040.

Irwin, D. E. (1996). Integrating information across saccadic eye movements. Current Directions in Psychological Science, 5(3), 94-100.

Irwin, D. E., Zacks, J. L., & Brown, J. S. (1989). Absence of spatiotopic interaction across saccades. Invest. Ophthalmol. Vis. Sci. (suppl), 39.

Irwin, D. E., Zacks, J. L., & Brown, J. S. (1990). Visual memory and the perception of a stable visual environment. Perception and Psychophysics, 47, 35- 46.

Ivry, R. B. (1992). Asymmetry in visual search for targets defined by differences in movement speed. Journal of Experimental Psychology: Human Perception & Performance, 18(4), 1045-1057.

Ivry, R. B., & Cohen, A. (1990). Dissociation of short- and long-range apparent motion in visual search. J. Exp. Psychol. - Human Perception and Performance, 16(2), 317-331.

James, W. (1890). The Principles of Psychology. New York: Henry Holt and Co.

Johnston, W. A., Hawley, K. J., & Farnham, J. M. (1993). Novel popout: Empirical boundaries and tentative theory. J. Experimental Psychology: Human Perception and Performance, 19(1), 140-153.

Joseph, J. S., Chun, M. M., & Nakayama, K. (1997). Attentional requirements in a "preattentive" feature search task. Nature, 387, 805.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Julesz, B. (1962). Visual pattern discrimination. IRE Trans Inf. Theory, IT-8, 84-92.

Julesz, B. (1964). Binocular depth perception without familiarty cues. . Science, 45, p356-362.

Julesz, B. (1971). Foundations of cyclopean perception. Chicago: University of Chicago.

Julesz, B. (1981). A theory of preattentive texture discrimination based on first order statistics of textons. Biological Cybernetics, 41, 131-138.

Julesz, B. (1984). A brief outline of the texton theory of human vision. Trends in Neuroscience, 7(Feb), 41-45.

Julesz, B. (1986). Texton gradients: The texton theory revisited. Biological Cybernetics, 54, 245-251.

Julesz, B., & Bergen, J. R. (1983). Textons, the fundamental elements in preattentive vision and perceptions of textures. Bell Sys. Tech. J., 62, 1619- 1646.

Julesz, B., Gilbert, E. N., Shepp, L. A., & Frisch, H. L. (1973). Inability of humans to discriminate between visual textures that agree in second-order statistics - revisited. Perception, 2, 391-405.

Julesz, B., & Krose, B. (1988). Features and spatial filters. Nature, 333, 302-303.

Julesz, B., & Papathomas, T. V. (1984). On spatial-frequency channels and attention. Perception and Psychophysics, 36(4), 398-399.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. R. Davies (Eds.), Varieties of Attention, (pp. 29-61). New York: Academic Press.

Kahneman, D., Treisman, A., & Gibbs, B. (1992). The reviewing of object files: Object -specific integration of information. Cognitive Psychology, 24, 179-219.

Kaptein, N. A., Theeuwes, J., & Van der Heijden, A. H. C. (1994). Search for a conjunctively defined target can be selectively limited to a color-defined subset of elements. J. Experimental Psychology: Human Perception and Performance, 21(5), 1053-1069.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Kawahara, J. I. (1993). The effect of stimulus motion on visual search. Japanese Journal of Psychology, 64(5), 396-400.

Keeble, D. R., & Morgan, M. J. (1993). A linear systems approach to texture perception. Investigative Ophthalmology and Visual Science, 34(4), 1237.

Keele, S. W., Cohen, A., Ivry, R., & Liotti, M. (1988). Tests of a temporal theory of attentional binding. Journal of Experimental Psychology: Human Perception & Performance, 14(3), 444-452.

Kim, M., & Cave, K. R. (1995). Spatial attention in visual search for features and feature conjunctions. Psychological Science, 6(6), 376-380.

Kimchi, R. (1992). Primacy of wholistic processing and global/local paradigm: A critical review. Psychological Bulletin, 112(1), 24-38.

Kinchla, R. A. (1992). Attention. Annual Review of Psychology, 43, 711-742.

Kinchla, R. A., & Wolfe, J. M. (1979). The order of visual processing: "Top-down", "bottom-up", or "middle-out". Perception and Psychophysics, 25, 225-231.

Kleffner, D. A., & Ramachandran, V. S. (1992). On the perception of shape from shading. Perception and Psychophysics, 52(1), 18-36.

Klein, R. (1988). Inhibitory tagging system facilitates visual search. Nature, 334, 430-431.

Koelega, H. S., Brinkman, J.-A., Hendriks, L., & Verbaten, M. N. (1989). Processing demands, effort, and individual differences in four different vigilance tasks. Human Factors, 31(1), 45-62.

Kramer, A., Cole, G. H., & Logan, G. D. (1996). Converging operations in the study of visual selective attention.. Washington, DC: American Psychological Association.

Kramer, A. F., Tham, M.-P., & Yeh, Y.-Y. (1991). Movement and focused attention: A failure to replicate. Perception and Psychophysics, 50(6), 537-546.

Krueger, L. E. (1984). The category effect in visual search depends on physical rather than conceptual differences. Perception and Psychophysics, 35(6), 558-564.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Krupinski, E. A., Nodine, C. F., & Kundel, H. L. (1993). Perceptual enhancement of tumor targets in chest X-ray images. Perception and Psychophysics, 53(5), 519-526.

Kurylo, D. D., Reeves, A., & Scharf, B. (1996). Expectancy of line segment orientation. Spatial Vision, 10(2), 149-162.

LaBerge, D. (1983). Spatial extent of attention to letters and words. J. Experimental Psychology: Human Perception and Performance, 9, 371-379.

LaGasse, L. L. (1993). Effects of good form and spatial frequency on global precedence. Perception and Psychophysics, 53(1), 89-105.

Lamb, M. R., & Robertson, L. C. (1990). The effect of visual angle on global and local reaction times depends on the set of visual angles presented. Perception and Psychophysics, 47(5), 489-496.

Lamb, M. R., & Yund, E. W. (1993). The role of spatial freqeuncy in the processing of hierachically organized stimuli. Perception and Psychophysics, 54(6), 773-784.

Landy, M. S., & Bergen, J. R. (1991). Texture segregation and orientation gradient. Vision Research, 31(4), 679-691.

Lankheet, M. J., & Verstraten, F. A. (1995). Attentional modulation of adaptation to two-component transparent motion. Vision Research, 35(10), 1401-1412.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. Journal of Experimental Psychology: Human Perception & Performance, 21(3), 451-468.

Lavie, N. (1996). Feature integration and selective attention: Response competition from unattended distractor features. Perception and Psychophysics, 59(4), 543-556.

Lavie, N., & Cox, S. (1996). On the effciency of visual selective attention: Efficient visual search leads to inefficient distractor rejection. Psychological Science, 8, 395-398.

Lavie, N., & Driver, J. (1996). On the spatial extent of attention in object-based visual selection. Perception and Psychophysics, 58, 1238-1251.

Lavie, N., & Tsal, Y. (1994a). Perceptual load as a major determinant of the locus of selection in visual attention. Perception & Psychophysics, 55(4), MS.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Lavie, N., & Tsal, Y. (1994b). Perceptual load as a major determinant of the locus of selection in visual attention. Perception and Psychophysics, 56(2), 183-197.

Levin, D. (1996). Classifying faces by race: The structure of face categories. Journal of Experimental Psychology: Learning, Memory, & Cognition, 22(6), 1364-1382.

Levin, D. T., & Simons, D. J. (1997). Failure to detect changes to attended objects in motion pictures. Psychological Bulletin and Review, in press.

Logan, G. D. (1996). The CODE theory of visual attention: An integration of space-based and object-based attention. Psychological Review, 103(4), 603-649.

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. Nature, 390(20 Nov), 279-281.

Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meanings can be accessed but not reported during the attentional blink. Nature, 382, 616-618.

Luschow, A., & Nothdurft, H. C. (1993). Pop-out of orientation but not pop-out of motion at isoluminance. Vision Research, 33(1), 91-104.

Mack, A., & Rock, I. (1996). Inattentional blindness: Perception without attention. In R. Wright (Ed.), Perception and Attention, .

Mack, A., Tang, B., Tuma, R., & Kahn, S. (1992). Perceptual organization and attention. Cognitive Psychology, 24, 475-501.

Mackie, R. R. e. (1977). Vigilance: Theory, operational performance and physiological correlates. New York: Plenum.

Malik, J., & Perona, P. (1990). Preattentive texture discrimination with early vision mechanisms. J. Opt. Soc. Am. A., 7(5), 923-932.

Mannan, S., Ruddock, K. H., & Wright, J. R. (1995). Eye movements and response times for the detection of line orientation during visual search. In J. M. Findlay, R. Walker, & Robert W. Kentridge (Eds.), Eye movement research: Mechanisms, processes and applications.Studies in visual information processing, (Vol. 6, pp. 337-348). Amsterdam, Netherlands: Elsevier Science Publishing Co, Inc.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

McElree, B., & Dosher, B. A. (1989). Serial position and set size in short-term memory: The time course of recognition. Journal of Experimental Psychology: General, 118(4), 346-373.

McLeod, P. (1993). Filtering and physiology in visual search: A convergence of behavioural and neurophysiological measures. In A. D. Baddeley & L. Weiskrantz (Eds.), Attention: Selection, awareness, and control: A tribute to Donald Broadbent, (pp. 72-86). Oxford, UK: Clarendon Press/Oxford University Press.

McLeod, P., Driver, J., & Crisp, J. (1988). Visual search for conjunctions of movement and form is parallel. Nature, 332, 154-155.

McLeod, P., Driver, J., Dienes, Z., & Crisp, J. (1991). Filtering by movement in visual search. J. Exp. Psychol. - Human Perception and Performance, 17(1), 55-64.

Miller, J. (1989). The control of visual attention by abrupt visual onsets and offsets. Perception and Psychophysics, 45, 567-571.

Miller, J. (1991). The flanker compatibility effect as a function of visual angle, attentional focus, visual transients, and perceptual load. Perception and Psychophysics, 49(3), 270-288.

Moraglia, G. (1989a). Display organization and the detection of horizontal lines segments. Perception and Psychophysics, 45, 265-272.

Moraglia, G. (1989b). Visual search: Spatial frequency and orientation. Perceptual & Motor Skills, 69(2), 675-689.

Moraglia, G., Maloney, K. P., Fekete, E. M., & Al-Basi, K. (1989). Visual search along the colour dimension. Canadian J of Psychology, 43(1), 1-12.

Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. Science, 229, 782-784.

Mordkoff, J. T., Yantis, S., & Egeth, H. E. (1990). Detecting conjunctions of color and form in parallel. Perception and Psychophysics, 48(2), 157-168.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Motter, B. C. (1994a). Neural correlates of attentive selection for color or luminance in extrastriate area V4. The Journal of Neuroscience, 14(4), 2178-2189.

Motter, B. C. (1994b). Neural correlates of feature selective memory and pop-out in extrastriate area V4. The Journal of Neuroscience, 14(4), 2190-2199.

Müller, H., & Found, A. (1996). Visual search for conjunctions of motion and form: Display density and asymmetry reversal. Journal of Experimental Psychology: Human Perception and Performance, 22(1), 122-132.

Müller, H., & Maxwell, J. (1994). Perceptual integration of motion and form information. J. Experimental Psychology: Human Perception and Performance, 20, 397-420.

Müller, H. J., & Findlay, J. M. (1987). Sensitivity and criterion effects in the spatial cuing of visual attention. Perception & Psychophysics, 42, 383-399.

Müller, H. J., Heller, D., & Ziegler, J. (1995). Visual search for singleton feature targets within and across feature dimensions. Perception and Psychophysics, 57(1), 1-17.

Müller, H. J., & von Muhlenen, A. (1996). Attentional tracking and inhibition of return in dynamic displays. Perception & Psychophysics, 58(2), 224-249.

Nagy, A. L., & Sanchez, R. R. (1990). Critical color differences determined with a visual search task. J. Optical Society of America - A, 7(7), 1209-1217.

Nagy, A. L., Sanchez, R. R., & Hughes, T. C. (1990). Visual search for color differences with foveal and peripheral vision. J. Optical Society of America - A, 7(10), 1995-2001.

Nakayama, K. (1990). The iconic bottleneck and the tenuous link between early visual processing and perception. Vision: Coding and Efficiency, 411-422.

Nakayama, K., & Mackeben, M. (1989). Sustained and transient components of focal visual attention. Vision Research, 29(11), 1631-1647.

Nakayama, K., & Silverman, G. H. (1986). Serial and parallel processing of visual feature conjunctions. Nature, 320, 264-265.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Navon, D. (1977). Forest before the trees: The precedence of global features in visual perception. Cognitive Psych., 9, 353-383.

Navon, D. (1990a). Does attention serve to integrate features? Psych. Rev., 97(3), 453-459.

Navon, D. (1990b). Treisman's search model does not require feature integration: Rejoinder to Treisman (1990). Psych. Rev., 97(3), 464-465.

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

Neumann, E., & DeSchepper, B. G. (1992). An inhibition-based fan effect: Evidence for an active suppression mechanism in selective attention. Canadian Journal of Psychology, 46, 1-40.

Nothdurft, H. C. (1991a). The role of local contrast in pop-out of orientation, motion and color. Investigative Ophthalmology and Visual Science, 32(4), 714.

Nothdurft, H. C. (1991b). Texture segmentation and pop-out from orientation contrast. Vision Research, 31(6), 1073-1078.

Nothdurft, H. C. (1992). Feature analysis and the role of similarity in pre-attentive vision. Perception and Psychophysics, 52(4), 355-375.

Nothdurft, H. C. (1993a). The role of features in preattentive vision: Comparison of orientation, motion and color cues. Vision Research, 33(14), 1937-1958.

Nothdurft, H. C. (1993b). Saliency effects across dimensions in visual search. Vision Research, 33(5/6), 839-844.

Nothdurft, H. C. (1993c). The conspicuousness of orientation and visual motion. Spatial Vision, 7(4), 341-366.

Nothdurft, H. C. (1993d). Faces and facial expression do not pop-out. Perception, 22, 1287-1298.

Nothdurft, H. C. (1994). Common properties of visual segmentation. In G. R. Bock & J. A. Goode (Eds.), Higher-order processing in the visual system, (pp. 245-259). Chicester, UK: John Wiley & Sons.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

O'Craven, K. M., Rosen, B. R., Kwong, K. K., & Treisman, A. (1997). Voluntary attention modulates fMRI activity in human MT-MST. Neuron, 18(April), 591-598.

O'Neill, P., & Wolfe, J. M. (1997). Individual differences in visual search or why testing two authors and one naive subject is inadequate. submitted 7/94.

O'Regan, J. K., Rensink, R., & Clark, J. J. (1996). "Mud splashes" render picture changes invisible. Investigative Ophthalmology and Visual Science, 37(3), S213.

O'Toole, A. J., & Walker , C. L. (1997). On the preattentive accessibility of stereoscopic disparity: Evidence from visual search. Perception & Psychophysics, 59(2), 202-218.

Owsley, C., Ball, K., & Keeton, D. M. (1995). Relationship between visual sensitivity and target localization in older adults. Vision Research, 35(4), 579-587.

Palmer, J. (1995). Attention in visual search: Distinguishing four causes of a set size effect. Current Directions in Psychological Science, 4(4), 118-123.

Palmer, J., Ames, C. T., & Lindsey, D. T. (1993). Measuring the effect of attention on simple visual search. Journal of Experimental Psychology: Human Perception & Performance, 19(1), 108-130.

Paquet, L. (1992). Global and local processing in nonattended objects: A failure to induce local processing dominance. J. Exp. Psychol: Human Perception and Performance., 18(2), 512-529.

Parasuraman, R. (1986). Vigilance, monitoring, and search. In K. R. Boff, L. Kaufmann, & J. P. Thomas (Eds.), Handbook of Human Perception and Performance, (1 ed., Vol. 2, pp. 43.1-43.39). New York: John Wiley and Sons.

Pashler, H. (1988). Familiarity and visual change detection. Perception and Psychophysics, 44, 369-378.

Pashler, H. (1997). The Psychology of Attention. Cambridge, MA: MIT Press.

Poisson, M. E., & Wilkinson, F. (1992). Distractor ratio and grouping processes in visual conjunction search. Perception, 21, 21-38.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Pomerantz, J. R., & Pristach, E. A. (1989). Emergent features, attention, and perceptual glue in visual form perception. J. Exp. Psychol. - Human Perception and Performance, 15(4), 635-649.

Ponte, D., Rechea, C., Sampedro, M. J., & Carrasco, M. (1997). A color X color conjunction can be searched in 'parallel'. Investigative Ophthalmology and Visual Science, 38(4), S365.

Posner, M. I., & Cohen, Y. (1984). Components of attention. In H. Bouma & D. G. Bouwhuis (Eds.), Attention and Performance X, (pp. 55-66). Hillside, NJ: Erlbaum.

Potter, M. C. (1975). Meaning in visual search. Science, 187, 965-966.

Potter, M. C. (1993). Very short-term conceptual memory. Memory & Cognition, 21(2), 156-161.

Potter, M. C., & Levy, E. I. (1969). Recognition memory for a rapid sequence of pictures. J. Experimental Psychology, 81, 10-15.

Pratt, J., & Abrams, R. A. (1995). Inhibition of return to successively cued spatial locations. J. Experimental Psychology: Human Perception and Performance, 21(6), 1343-1353.

Previc, F. H. (1996). Attentional and oculomotor influences on visual field anisotropies in visual search performance. Visual Cognition, 3(3), 277-301.

Previc, F. H., & Blume, J. L. (1993). Visual search asymmetries in three-dimensional space. Vision Research, 33(18), 2697-2704.

Prinzmetal, W., Henderson, D., & Ivry, R. (1995). Loosening the constraints on illusory conjunctions: the role of exposure duration and attention. Journal of Experimental Psychology: Human Perception and Performance,, 21(6), 1362-1375.

Prinzmetal, W., & Keysar, B. (1989). Functional theory of illusory conjunctions and neon colors. Journal of Experimental Psychology:General, 118(2), p165-190.

Purcell, D. G., Stewart, A. L., & Skov, R. B. (1996). It takes a confounded face to pop out of a crowd. Perception, 25(9), 1091-1108.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Pylyshyn, Z., & Storm, R. W. (1988). Tracking multiple independent targets:evidence for a parallel tracking mechanism. Spatial Vision, 3, 179-197.

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

Pylyshyn, Z. W. (1994). Some primitive mechanisms of spatial attention. Cognition, 50, 363-384.

Pylyshyn, Z. W. (1998). Visual indexes in spatial perception and mental imagery. In R. W. (Ed.) (Ed.), Vision and Attention, (pp. in press). New York: Oxford U. Press.

Ramachandran, V. S. (1988). Perception of shape from shading. Nature, 331, 163-165.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? J. Experimental Psychology: Human Perception and Performance, 18(3), 849-860.

Redding, G. M., & Wallace, B. (1985). Cognitive interference in prism adaptation. . Perception and Psychophhysics, 37, p225-231.

Rees, G., Frith, C., & Lavie, N. (1997). Modulating irrelevant motion perception by varying attentional load in an unrelated task. Science, 278(5343), 1616-1619.

Reinitz, M. T., Morrissey, J., & Demb, J. (1994). Role of attention in face encoding. Journal of Experimental Psychology: Learning, Memory, and Cognition, 20(1), 161-168.

Remington, R. W., Johnston, J. C., & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. Perception and Psychophysics, 51(3), 279-290.

Rensink, R., & Cavanagh, P. (1993). Processing of shadows at preattentive levels. Investigative Ophthalmology and Visual Science, 34(4), 1288.

Rensink, R., O'Regan, J. K., & Clark, J. J. (1995). Image flicker is as good as saccades in making large scene changes invisible. Perception, 24 (suppl), 26-27.

Rensink, R., O'Regan, J. K., & Clark, J. J. (1996b). To see or not to see: The need for attention to perceive changes in scenes. Psychological Science, 8, 368-373.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Rensink, R., O'Regan, J. K., & Clark, J. J. (1996a). To see or not to see: The need for attention to perceive changes in scenes. Investigative Ophthalmology and Visual Science, 37(3), S213.

Rensink, R. A., & Enns, J. T. (1995). Pre-emption effects in visual search: evidence for low-level grouping. Psychological Review, 102(1), 101-130.

Richards, W. (1968). Spatial remapping in the primate visual system. Kybernetik, 4, 146-156.

Riggs, L. A. (1973). Curvature as a feature of pattern vision. . Science, 181, p1070--1072.

Robertson, L. C., Egly, R., Lamb, M. R., & Kerth, L. (1993). Spatial attention and curing to global and local levels of hierarchical structure. J. Exp. Psychol. - Human Perception and Performance, 19(3), 471-487.

Rossi, A., & Paradiso, M. A. (1995). Feature-specific effects of selective visual attention. Vision Research, 35, 621-634.

Royden, C. S., Wolfe, J. M., Konstantinova, E., & Hildreth, E. C. (1996). Search for a moving object by a moving observer. Investigative Opthalamology and Visual Science, 37(3), S299.

Royden, C. S., Wolfe, J. M., Konstantinova, E., & Hildreth, E. C. (1997). Search for a moving object by a moving observer: Locating a static object among moving distractors. Paper presented at the Annual meeting of the Cognitive Neuroscience Society, Boston.

Rubin, J. M., & Kanwisher, N. (1985). Topological perception: Holes in an experiment. Perception and Psychophysics, 37, 179-180.

Saarinen, J. (1995). Visual search at different spatial scales. Scandinavian Journal of Psychology, 36(1), 1-9.

Saarinen, J. U. H., Dept of Psychology, Finland], TITLE:, Perception, P. I., 0301-0066, I., & 237-243, V. (1994). Visual search for global and local stimulus features. 23, 2(2), 237-243.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Sagi, D. (1988). The combination of spatial frequency and orientation is effortlessly perceived. Perception and Psychophysics, 43, 601-603.

Sagi, D., & Julesz, B. (1985). Fast noninertial shifts of attention. Spatial Vision, 1, 141-149.

Sagi, D., & Julesz, B. (1986). Enhanced detection in the aperture of focal attention during simple discrimination tasks. Nature, 321, 693-695.

Sanders, A. F. (1970). Some aspects of the selective process in the functional visual field. Ergonomics, 13(1), 101-117.

Sanders, A. F. (1993). Processing information in the function visual field. In G. d'Ydewalle & J. VanRensbergen (Eds.), Perception and Cognition, (pp. 3-22). Amsterdam: Elsevier Science.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. Psychol. Rev., 84, 1-66.

Schneider, W. X. (1993). Space-based visual attention models and object selection: Constraints, problems, and possible solutions. Psychological Research, 56, 35-43.

Sekuler, R., & Ball, K. (1986). Visual localization: Age and practice. J. Optical Society of America - A, 3(6), 864-868.

Shapiro, K., Driver, J., Ward, R., & Sorenson, R. E. (1997). Priming from the attentional blink. Psychological Science, 8(2), 95-100.

Shapiro, K. L. (1994). The attentional blink: The brain's eyeblink. Current Directions in Psychological Science, 3(3), 86-89.

Shiffrin, M. R., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psych. Review, 84, p127-190.

Shiffrin, R. M. (1988). Attention. In R. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), Steven's Handbook of Experimental Psychology., (2nd ed., Vol. 2, pp. 739-812). New York: John Wiley & Sons.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Shih, S.I., & Sperling, G. (1996). Is there feature-based attentional selection in visual search. J. Experimental Psychology: Human Perception and Performance, 22(3), 758-779.

Shimojo, S., Miyauchi, S., & Hikosaka, O. (1992). Voluntary and involuntary attention directed by the line-motion effect. Perception, 22(supplement 2 (ECVP - Pisa)), 12.

Shulman, G. L. (1991). Attentional modulation of mechanisms that analyze rotation in depth. Journal of Experimental Psychology: Human Perception and Performance, 17(3), 726-737.

Shulman, G. L. (1992). Attentional modulation of a figural aftereffect. Perception, 21, 7-19.

Shulman, G. L. (1993a). Attentional effects on adaptation of rotary motion in the plane. Perception, 22, 947-961.

Shulman, G. L. (1993b). Attentional effects on Necker cube adaptation. Canadian Journal of Experimental Psychology, 47(3), 540-547.

Simmons, D. R., & Foster, D. H. (1992). Segmenting textures of curved-line elements. In G. A. Orban, Nagel, H H (Ed.), Artificial and Biological Vision Systems, (pp. MS): Springer-Verlag.

Simons, D. J. (1996). In sight, out of mind. Psychological Science, 7(5), 301-305.

Simons, D. J., & Levin, D. T. (1997a). Change blindness. Trends in Cognitive Sciences, 1(7), 261-267.

Simons, D. J., & Levin, D. T. (1997b). Failure to detect changes to attended objects. Investigative Ophthalmology and Visual Science., 38(4), S707.

Smallman, H. S., & Boynton, R. M. (1990). Segregation of basic color in an information display. J. Optical Society of America - A, 7(10), 1985-1994.

Smith, S. L. (1962). Color coding and visual search. J. Exp. Psychol., 64, 434-440.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Snyder, A. W., & Barlow, H. B. (1988). Revealing the artist's touch. Nature, 331, 117-118.

Solomon, J. A., Lavie, N., & Morgan, M. J. (1997). The contrast discrimination function: spatial cuing effects. Journal of the Optical Society of America, 14, 2443-2448.

Sperling, G., Budiansky, J., Spivak, J., & Johnson, M. C. (1971). Extremely rapid visual search. The maximum rate of scanning letters for the presence of a numeral. Science, 174, 307-311.

Sperling, G., Weichselgartner, E. (1995). Episodic theory of the dynamics of spatial attention. Attention & Psychological Review, 102(3), 503-532.

Spitzer, H., Desimone, R., & Moran, J. (1988). Increased attention enhances both behavioral and neuronal performance. Science, 240, 338-340.

Stelmach, L. B., Herdman, C. M., & MacNeil, K. R. (1994). Attentional modulation of visual processes in motion perception. J. Experimental Psychology: Human Perception and Performance, 20(1), 108-121.

Sternberg, S. (1969). High-speed scanning in human memory. Science, 153, 652-654.

Stromeyer, C. F., & Riggs, L. A. (1974). Curvature detectors in human vision? Science, 184, p1199-1201.

Stuart, G. W. (1993). Preattentive processing of object size: Implications for theories of size perception. Perception, 22(10), 1175-1193.

Styles, E. A. (1997). The Psychology of Attentipon. Hove, East Sussex, UK: The Psychology Press.

Sun, J., & Perona, P. (1996a). Preattentive perception of elementary three dimensional shapes. Vision Research, 36(16), 2515-2529.

Sun, J., & Perona, P. (1996b). Where is the sun? Investigative Ophthalmology and Visual Science, 37(3), S935.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Suzuki, S., & Cavanagh, P. (1995). Facial organization blocks access to low-level features: An object inferiority effect. Journal of Experimental Psychology: Human Perception and Performance, 21(4), 901-913.

Swensson, R. G. (1980). A two-stage detection model applied to skilled visual search by radiologists. Perception and Psychophysics, 27(1), 11-16.

Swensson, R. G., & Judy, P. F. (1981). Detection of noisy visual targets: Models for the effects of spatial uncertainty and signal -to-noise ratio. Perception and Psychophysics, 29(6), 521-534.

Takeuchi, T. (1997). Visual search of expansion and contraction. Vision Research, 37(5), 2083-2090.

Taylor, S., & Badcock, D. (1988). Processing feature density in preattentive perception. Perception and Psychophysics, 44, 551-562.

Theeuwes, J. (1991). Exogenous and edongenous control of attention: The effect of visual onsets and offsets. Perception and Psyhcophysics, 49(1), 83-90.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. J. Experimental Psychology: Human Perception and Performance., 20(4), 799-806.

Theeuwes, J. (1995). Abrupt luminance change pops out; abrupt color change does not. Perception & Psychophysics, 57(5), 637-644.

Theeuwes, J., & Kooi, J. L. (1994). Parallel search for a conjunction of shape and contrast polarity. Vision Research, 34(22), 3013-3016.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. Quart. J. Experimental Psychology, 37A, 571-590.

Tipper, S. P., & Cranston, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. Quart. J. Experimental Psychology, 37A, 591-611.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Tipper, S. P., & Driver, J. (1988). Negative priming between pictures and words in a selective attention task: Evidence for semantic processing of ignored stimuli. Memory and Cognition, 16(1), 64-70.

Tipper, S. P., & Weaver, B. (1996). The medium of attention: Location-based, object-based, or scene-based? In R. Wright (Ed.), Visual Attention, : Oxford U. Press.

Tipper, S. P., Weaver, B., Jerreat, L. M., & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. Journal of Experimental Psychology: Human Perception & Performance, 20(3), 478-499.

Tipper, S. P., Weaver, B., & Watson, F. L. (1996). Inhibition of return to successively cued spatial locations: Commentary on Pratt and Abrams (1995). Journal of Experimental Psychology: Human Perception & Performance, 22(5), 1289-1293.

Townsend, J. T. (1971). A note on the identification of parallel and serial processes. Perception and Psychophysics, 10, 161-163.

Townsend, J. T. (1976). Serial and within-stage independent parallel model equivalence on the minimum completion time. J. Mathematical Psychology, 14, 219- 239.

Townsend, J. T. (1990). Serial and parallel processing: Sometimes they look like Tweedledum and Tweedledee but they can (and should) be distinguished. Psychological Science, 1, 46-54.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. Journal of Experimental Psychology: Human Perception and Performance., 8, 194-214.

Treisman, A. (1985). Preattentive processing in vision. Computer vision, graphics, and image processing., 31, 156-177.

Treisman, A. (1986). Properties, parts, and objects. In K. R. Boff, L. Kaufmann, & J. P. Thomas (Eds.), Handbook of Human Perception and Performance, (1 ed., Vol. 2, pp. 37.1-35.70). New York: John Wiley and Sons.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Treisman, A. (1988). Features and objects: The 14th Bartlett memorial lecture. Quart. J. Exp. Psychol., 40A, 201-237.

Treisman, A. (1990). Variations on a theme of feature integration. Reply to Navon (1990). Psych. Rev., 97(3), 460-463.

Treisman, A. (1991). Spreading suppresion or feature integration? A reply to Duncan and Humphreys. , MS, 1-21.

Treisman, A. (1992). Spreading suppression or feature integration? A reply to Duncan and Humphreys (1992). J. Exp. Psychol. - Human Perception and Performance, 18(2), 589-593.

Treisman, A., & DeSchepper, B. (1996). Object tokens, attention, and visual memory. In T. Inui & J. McClelland (Eds.), Attention and Performance XVI: Information Integration in Perception and Communication, (pp. 15-46). Cambridge, MA: MIT Press.

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

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. Psych. Review, 95, p15-48.

Treisman, A., & Sato, S. (1990). Conjunction search revisited. J. Exp. Psychol: Human Perception and Performance, 16(3), 459-478.

Treisman, A., & Souther, J. (1985). Search asymmetry: A diagnostic for preattentive processing of seperable features. J. Exp. Psychol. - General, 114, 285-310.

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

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

Treue, S., & Maunsell, J. H. R. (1996). Attentional modulation of visual motion processing in cortical areas MT and MST. Nature, 382(8 aug), 539-541.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Trick, L. M., & Enns, J. T. (1997). Measuring preattentive processes: When is pop-out not enough? Visual Cognition, 4(2), 163-198.

Tsal, Y. (1983). Movement of attention across the visual field. Journal of Experimental Psychology: Human Perception & Performance, 9(4), 523-530.

Tsal, Y. (1989a). Do illusory conjunctions support feature integration theory? A critical review of theory and findings. J. Exp. Psychol. - Human Perception and Performance, 15(2), 394-400.

Tsal, Y. (1989b). Further comments on feature integration theory. A reply to Briand and Klein. J. Exp. Psychol. - Human Perception and Performance, 15(2), 407-410.

Tsal, Y., & Lavie, N. (1993). Location dominance in attending to color and shape. Journal of Experimental Psychology: Human Perception and Performance, 19, 131-139.

Tsal, Y., Meiran, N., & Lavie, N. (1994). The role of attention in illusory conjunctions. Perception and Psychophysics, 55(3), 350-358.

Tse, P., Cavanagh, P., & Nakayama, K. (1998). The Role of Parsing in High-Level Motion Processing. In T. Watanabe (Ed.), High-level Motion Processing, . Cambridge, MA: MIT Press.

Tyler, C. W. (1983). Sensory processing of binocular disparity. In C. W. Schor & K. J. Ciuffreda (Eds.), Vergence Eye Movements, (pp. 199-295). Boston: Butterworth.

Urbach, D., & Spitzer, H. (1995). Attentional effort modulated by task difficulty. Vision Research, 35(15), 2169-2177.

Van Orden, K. F. (1993). Redundant use of luminance and flashing with shape and color as highlighting codes in symbolic displays. Human Factors, 35(2), 195-204.

Van Zandt, T., & Townsend, J. T. (1993). Self-terminating versus exhaustive processes in rapid visual and memory search: An evaluative review. Perception and Psychophysics, 53(5), 563-580.

Vecera, S. P., & Farah, M. J. (1994). Does visual attention select objects or locations? J. Experimental Psychology: General, 123(2), 146-160.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Verghese, P., & Nakayama, K. (1994). Stimulus discriminability in visual search. Vision Research, 34(18), 2453-2467.

Verghese, P., & Pelli, D. G. (1994). The scale bandwidth of visual search. Vision Research, 34(7), 955-962.

Von der Heydt, R., Peterhans, E., & Baumgartner, G. (1984). Illusory contours and cortical neuron responses. Science, 224, 1260-1262.

von Grunau, M., & Anston, C. (1995). The detection of gaze direction: A stare-in-the-crowd effect. Perception, 24(11), 1297-1313.

Von Grünau, M., & Dubé, S. (1994). Visual search asymmetry for viewing direction. Perception and Psychophysics, 56(2), 211-220.

von Grünau, M., Dubé, S., & Kwas, M. (1996). Two contributions to motion induction: A preattentive effect and facilitation due to attentional capture. Vision Research, 36, 2447-2457.

vonGrunau, M., & Faubert, J. (1992). Interactive effects in motion induction. Perception, 22(supplement 2 (ECVP - Pisa)), 12.

Wang, Q., & Cavanagh, P. (1993). Aquired familiarity effects in visual search with chinese characters. Investigative Ophthalmology and Visual Science, 34(4), 1236.

Wang, Q., Cavanagh, P., & Green, M. (1994). Familiarity and pop-out in visual search. Perception and Psychophysics, 56(5), 495-500.

Ward, R., Duncan, J., & Shapiro, K. (1996). The slow time-course of visual attention. Cognitive Psychology, 30(1), 79-109.

Ward, R., Duncan, J., & Shapiro, K. (1997). Effects of similarity, difficulty, and nontarget presentation on the time course of visual attention. Perception and Psychophysics, 59(4), 593-600.

Weisstein, N. (1973). Beyond the yellow Volkswagen detector and the grandmother cell: A general strategy for the exploration of operations in human pattern recognition. In R.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

L. Solso (Ed.), Contemporary issues in cognitive psychology: The Loyola Symposium., . Washington, DC: Winston/Wiley.

Weltman, G., & Egstrom, G. H. (1966). Perceptual narrowing in novice divers. Human Factors, 8, 499-506.

Williams, L. G. (1966a). The effect of target specification on objects fixated during visual search. Perception & Psychophysics, 1, 315-318.

Williams, L. G. (1966b). The effect of target specification on objects fixed during visual search. Perception and Psychophysics, 1, 315-318.

Williams, L. J. (1985). Tunnel vision induced by a foveal load manipulation. Human Factors, 27(2), 221-227.

Williams, L. J. (1989). Foveal load effects the functional field of view. Human Performance, 2(1), 1-28.

Wolfe, J. M. (1986). Stereopsis and binocular rivalry. Psych. Review, 93, 269-282.

Wolfe, J. M. (1992a). "Effortless" texture segmentation and "parallel" visual search are *not* the same thing. Vision Research, 32(4), 757-763.

Wolfe, J. M. (1992b). The parallel guidance of visual attention. Current Directions in Psychological Science, 1(4), 125-128.

Wolfe, J. M. (1994). Guided Search 2.0: A revised model of visual search. Psychonomic Bulletin and Review, 1(2), 202-238.

Wolfe, J. M. (1996). Extending Guided Search: Why Guided Search needs a preattentive "item map". In A. Kramer, G. H. Cole, & G. D. Logan (Eds.), Converging operations in the study of visual selective attention., (pp. 247-270). Washington, DC: American Psychological Association.

Wolfe, J. M. (1997a). Inattentional amnesia. Abstracts of the Psychonomic Society, 2(Nov 1997), 18.

Wolfe, J. M. (1997b). Visual search. In H. Pashler (Ed.), Attention, . London, UK: University College London Press.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Wolfe, J. M. (1997c). What do 1,000,000 trials tell us about visual search? Psychological Science, in press.

Wolfe, J. M., & Bennett, S. C. (1997). Preattentive Object Files: Shapeless bundles of basic features. Vision Research, 37(1), 25-44.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided Search: An alternative to the Feature Integration model for visual search. J. Exp. Psychol. - Human Perception and Perf., 15, 419-433.

Wolfe, J. M., Chun, M. M., & Friedman-Hill, S. R. (1993). Making use of texton gradients: Visual search and texton grouping exploit the same parallel processes in different ways. Spatial Vision, 7(1), 90 (abstract only).

Wolfe, J. M., & Franzel, S. L. (1988). Binocularity and visual search. Perception and Psychophysics, 44, 81-93.

Wolfe, J. M., & Friedman-Hill, S. R. (1992a). On the role of symmetry in visual search. Psychological Science, 3(3), 194-198.

Wolfe, J. M., & Friedman-Hill, S. R. (1992b). Visual search for orientation: The role of angular relations between targets and distractors. *Spatial Vision*, 6(3), 199-208.

Wolfe, J. M., Friedman-Hill, S. R., & Bilsky, A. B. (1994). Parallel processing of part/whole information in visual search tasks. Perception and Psychophysics, 55(5), 537-550.

Wolfe, J. M., Friedman-Hill, S. R., Stewart, M. I., & O'Connell, K. M. (1992a). The role of categorization in visual search for orientation. J. Exp. Psychol: Human Perception and Performance, 18(1), 34-49.

Wolfe, J. M., Klempen, N., & Dahlen, K. (1998). Post-attentive vision. submitted 12/97.

Wolfe, J. M., O'Neill, P. E., & Bennett, S. C. (1997). Why are there eccentricity effects in visual search? Perception and Psychophysics, in press.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Wolfe, J. M., & Pokorny, C. W. (1990). Inhibitory tagging in visual search: A failure to replicate. Perception and Psychophysics, 48, 357-362.

Wolfe, J. M., Yee, A., & Friedman-Hill, S. R. (1992b). Curvature is a basic feature for visual search. Perception, 21, 465-480.

Wolfe, J. M., Yu, K. P., Stewart, M. I., Shorter, A. D., Friedman-Hill, S. R., & Cave, K. R. (1990). Limitations on the parallel guidance of visual search: Color X color and orientation X orientation conjunctions. J. Exp. Psychol: Human Perception and Performance, 16(4), 879-892.

Yantis, S. (1992). Multielement visual tracking: Attention and perceptual organization. Cognitive Psychology, 24, 295-340.

Yantis, S. (1993). Stimulus-driven attentional capture. Current Directions in Psychological Science, 2(5), 156-161.

Yantis, S., & Hillstrom, A. P. (1994). Stimulus-driven attentional capture: Evidence from equiluminant visual objects. J. Experimental Psychology: Human Perception and Performance, 20(1), 95-107.

Yantis, S., & Johnson, D. N. (1990). Mechansims of attentional priority. J. Exp. Psychol. - Human Perception and Performance, 16(4), 812-825.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: voluntary versus automatic allocation. J. Exp. Psychol. - Human Perception and Performance, 16(1), 121-134.

Yeh, S.-L., Chen, I. P., De Valois, K. K., & De Valois, R. L. (1996). Figural aftereffects and spatial attention. Journal of Experimental Psychology: Human Perception & Performance, 22(2), 446-460.

Yund, E. W. (1996). Guided search: The effects of learning. Brain & Cognition, 31(3), 369-386.

Yund, E. W., Efron, R., & Nichols, D. R. (1990). Detectability gradients as a function of target location. Brain and Cognition, 12, 1-16.

Wolfe J. Visual attention. In: De Valois KK, editor. Seeing. 2nd ed. San Diego, CA: Academic Press; 2000. p. 335-386.

Zelinsky, G. J., Rao, R. P. N., Hayhoe, M. M., & Ballard, D. H. (1996). Eye movements reveal the spatio-temporal dynamics of visual search. Psychological Science, 8(6), 448-453.

Zelinsky, G. J., & Sheinberg, D. L. (1997). Eye movements during parallel / serial visual search. J. Experimental Psychology: Human Perception and Performance, 23(1), 244-262.

Zohary, E., Hochstein, S., & Hillman, P. (1988). Parallel and serial processing in detecting conjunctions. Perception, 17, 416.