7.

SOME REFLECTIONS ON THE PROCESSING OF PERCEPTUAL FEATURES

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One of Anne Treisman's major contributions is the feature-integration theory (FIT) of attention. Broadly speaking, this theory can be characterized as a two-stage framework for visual search and other perceptual tasks. In the first, preattentive, stage, stimuli are represented in maps of elemental features such as color, size, motion, and orientation:

"...basic features are coded (1) automatically, (2) without focused attention, and (3) spatially in parallel" (1988, p. 203, numbering added). A second, attentive, stage, based on a salience map, is required for the accurate localization and combination of features. This theory has had a huge impact on the field. It is still generating work that addresses issues that Treisman brought to our attention. The literature generated by Treisman's theorizing is so voluminous that it cannot properly be reviewed in a short chapter like this, so I have decided to focus on the role of attention in the detection of elemental features. This approach largely eliminates from consideration the topics of conjunction search and illusory conjunctions, as well as most considerations of the two-stage architecture itself (e.g., is it possible to know that a feature is present without being able to localize it). I will discuss the three key topics in the quote above, although in a different order.

SPATIAL PARALLELISM

Treisman and Gelade (1980) found that the time required to detect the presence of a featural singleton (e.g., the only blue item in a display of items that were otherwise all green or brown), was independent of display size. They proposed that elemental features could be detected *preattentively*. This was, of course, not the first time the notion of preattentive processing had been introduced into psychology. Notably, Neisser (1967) described preattentive processes as being spatially parallel operations that create basic representations from which more sophisticated representations can be constructed. In the realm of visual search, several investigators had previously observed "pop out" of featurally distinctive targets, that is, that the amount of time required to detect a target could be independent of the number of items through which subjects had to search (e.g., Donderi & Zelnicker, 1969; Egeth, Jonides, & Wall, 1972). However, Treisman and her colleagues were the first to place this phenomenon in a broad theoretical context, one based on the notion of feature maps that could help explain results from conjunction searches as well.

In a historical overview of FIT, Quinlan (2003) summarized the state of the theory as of the early 1990s as follows: "Featural pop-out arises because of the presence of a distinctive feature value signaled on a particular feature map" (p. 654). Thus, if a subject is searching for a blue character in a display consisting of a number of green characters and brown characters, all that the visual system has to do is consult the "blue map." If there is activity in that map, then a blue character is present. As the blue map has input from the entire visual field, spatial parallelism is accounted for in a natural way. (Of course, as Treisman pointed out, one does not want to push the notion of spatial parallelism too far. If the visual field becomes too densely populated with stimuli, lateral masking and crowding effects will start to degrade performance.)

When psychologists describe the kind of search studies on which Treisman's theory is based, they will typically refer to something like "search for a red item in a field of green distractors." The original experiments were, as mentioned earlier, a bit more complicated; subjects searched for a target among mixed distractors (e.g., a blue item among green and brown distractors). In fact, subjects were actually faced with an even more complicated task: search for a blue letter or an S among green X's and brown T's. (This instruction was used for the sake of having displays that were as complex as those used in the conjunction search conditions in which subjects might search for, say, a green T among green X's and brown T's.) In any case, target-present reaction times (RTs) were shallow; with the slope of the function relating RT to display size in the range of 2–4 milliseconds per item for color or form. The fact that slopes were so shallow even though the distractors were not completely homogeneous is interesting in its own right; it shows that the preattentive system can tolerate a bit of nontarget heterogeneity (see Duncan and Humphreys [1989] for a fuller account of the effects of nontarget heterogeneity). The results also have a complication—although the RT vs. display size function was essentially flat for target-present responses, there was often a substantial slope for target-absent responses (e.g., about 25 milliseconds per item for color and form). This is not always the case; sometimes target-absent RTs are as flat as target-present RTs (e.g., Donderi & Zelnicker, 1969; Egeth, Jonides, & Wall, 1972, Exps. 1 and 2). In any case, RTs for negative responses are frequently a puzzle, and we will not dwell on them in this brief chapter (cf. Krueger, 1978; Chun & Wolfe, 1996).

Other investigators have obtained similar results in which simple searches have yielded flat, nearly flat, or even negatively sloped RT versus display-size functions. If we take the slope of the RT versus display-size function as a measure of efficiency of processing, then feature search appears to be highly efficient (for a review, see Wolfe, 1998). Early efforts to characterize processing in various tasks often referred to near-zero slopes as indicative of unlimited-capacity parallel processing (e.g., Egeth, Jonides, & Wall, 1972; Townsend, 1971), an interpretation that is congenial to the thrust of FIT.

It is instructive to consider cases in which parallel processing appears to break down—that is, where feature searches do not result in flat slopes. One such situation occurs when the target does or does not contain a particular feature. For example, Treisman and Souther (1985) found that search for a Q among Os yields a shallow RT function (slope around 3 milliseconds per item), whereas search for an O among Qs yields a steep function (slope near 40 milliseconds per item). This sort of *search asymmetry* has been found not just with the presence versus absence of a feature but also when targets and distractors differ in degree along a quantitative dimension. For example, with stimuli composed of line segments, search for a long target among short distractors yields a significantly shallower slope than search for a short target among long distractors (Treisman and Gormican, 1988). The slopes in some of these searches are sometimes substantial. This may imply item-by-item serial processing; alternatively, the results may imply that groups of items are searched serially, with the items within a group processed in parallel (cf. Treisman, 1982; Pashler, 1987). The size of the group so processed would depend on target-distractor similarity.

Of course, we have known for a long time (e.g., Atkinson, Holmgren, & Juola, 1969; Townsend, 1971) that nonflat functions do not necessarily imply serial processing. One possible interpretation is that the inefficiency implied by these set-size effects when target-distractor similarity is high reflects an attentional capacity limit. However, it is possible that when the processing of each item is at all degraded, a display-size effect emerges for reasons unrelated to attentional capacity limitations (e.g., Eckstein, Thomas, Palmer, & Shimozaki, 2000; Eriksen, & Spencer, 1969; Huang & Pashler, 2005; ~~and~~ Palmer, 1994). In the context of visual search, Eriksen and Spencer (1969) were perhaps the first to point out that, as long as there is some nonzero probability of mistaking a target for a distractor when display size is 1, then that probability will naturally increase as display size increases—without assuming that larger displays require more capacity. If subjects tend to try to maintain error rates at about the same level across conditions, this would result in longer RTs for larger display sizes.

Huang and Pashler (2005) attempted to directly test capacity limits in three kinds of search: a feature search (a small square among larger squares), a conjunction search (a large vertical rectangle among small vertical, small horizontal, and large horizontal rectangles), and a spatial-configuration search (rotated T's among rotated L's). Subjects performed these searches in two different tasks. One was an ordinary search task with display sizes of 8 and 16 in which RT was the variable of chief interest. The other task, which assessed accuracy of performance, was one first introduced by Eriksen and Spencer (1969) and modified by Shiffrin and Gardner (1972), who referred to it as the SIM-SUCC task (for simultaneous versus successive). On each trial, Huang and Pashler (2005) presented their subjects with 16-item displays, sometimes all at once (SIM), and sometimes in two successive 8-item portions (SUCC). In both SIM and SUCC displays, every element was presented for the same amount of time before being masked. Thus, if the SIM display was 150 milliseconds, then the SUCC displays would each be displayed for 150 milliseconds, with some interdisplay interval, say, 500 milliseconds. Both kinds of displays were masked. The logic of the SIM-SUCC comparison is that, if processing capacity is limited, then subjects should perform better when they can focus on half of the 16 items at a time (i.e., in the SUCC condition) than when they have to spread their attention over the entire 16 items at once.

Huang and Pashler found that search RT increased substantially for all three kinds of search as display size increased from 8 to 16. However the SIM-SUCC results were markedly different for the three searches. There is previous research suggesting the spatial configuration search is attentionally demanding (e.g., Bergen & Julesz, 1983; Egeth & Dagenbach, 1991), and typically has higher search slopes than the other two kinds of searches (e.g., Wolfe, 1998), even though it can be conceived of as a special case of conjunction search. Thus, it was not surprising to find that there was a significant advantage for the SUCC condition compared to the SIM condition for the spatial-configuration search. However, for both the feature search and the conjunction search, there was no significant advantage of SUCC over SIM. Despite the display-size effect found in the search task, there was no evidence that either of these two searches introduced attentional capacity limits. Given that the subtle size discrimination used by Huang and Pashler did not involve capacity limits, it seems, *a fortiori*, that easy feature searches will not either, just as predicted by FIT.

Although this chapter is focused on feature identification, it is worth mentioning that Huang and Pashler's results for conjunction search are consistent with several others in the literature, suggesting that conjunction search may not require serial attention to display elements, contrary to the early claims of FIT (e.g., Eckstein et al., 2000; Wolfe, Cave, & Franzel, 1989; Mordkoff, Yantis, & Egeth, 1990).

ARE FEATURES CODED AUTOMATICALLY?

There are several criteria that have been advanced in efforts to define the concept of automaticity (e.g., Jonides, Naveh-Benjamin, & Palmer, 1985; Kahneman& Treisman, 1984; Treisman, Vieira, & Hayes, 1992). One of the criteria is spatially parallel processing. As we have just seen, feature detection would appear to meet that criterion. Another commonly used criterion is that an automatic process should not be hindered when concurrent information load is increased. What happens when feature detection is carried out under condition of varying concurrent load?

DUAL-TASK EXPERIMENTS

Some results strikingly at odds with FIT have been obtained in a dual-task experiment conducted by Joseph, Chun, and Nakayama (1997). In a preliminary study, they presented subjects with a display of Gabor patches and had subjects indicate if they were all oriented in the same direction (+ or −45 degrees from vertical; 50 percent of trials), or whether one of the patches was misoriented by 90 degrees from the others (50 percent of trials). The chief finding was that RT to detect an orientation singleton was independent of the number of Gabor patches. This confirmed the earlier conclusion that orientation differences could be detected preattentively (e.g., Treisman & Gormican, 1988; Sagi & Julesz, 1985).

In the main study, Joseph and colleagues used a dual-task; more specifically, they made use of the attentional-blink paradigm. The attentional blink is usually taken to reflect the effect of a temporary depletion of resources attendant upon the need to identify the first of two targets in a stream. As diagrammed in figure 7.1, they presented a rapid serial visual presentation (RSVP) stream of black letters at fixation. There were two targets. The first was a white letter embedded in the stream; after a variable interval this was followed by the second target, which was a ring of Gabor patches surrounding one of the letters in the stream, at an eccentricity of 5.3 degrees. The tasks were to name the white letter and indicate if all the Gabor patches were oriented in the same direction or if one patch was misoriented by 90 degrees from the others. In a single-task control condition subjects could ignore the RSVP stream and just report on the Gabor patches. Performance on the control task was over 90 percent correct, and was independent of the lag between the white letter and the Gabor patches. In the experimental condition, performance was poor (about 60 percent correct, where chance was 50 percent) when the Gabor patches were simultaneous with the white target (lag = 0), and improved steadily to nearly 90 percent correct when the lag was 700 milliseconds. The authors argue that this large dual-task decrement is incompatible with the notion that detection of an orientation singleton is preattentive.

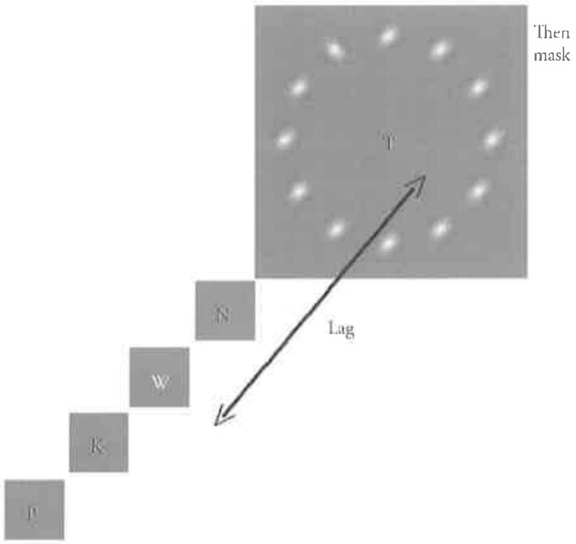

Figure 7.1 Schematic of the displays used by Joseph, Chun, and Nakayama (1997). Gabor patches were oriented 45 degrees clockwise or counterclockwise from vertical. Half of the trials were homogeneous with respect to orientation; the other half had one misoriented item. The letter stream was presented at fixation at a rate of 12 letters per second. See text for further details.

In the following section, I sketch out some of the issues that have come up as this finding has been discussed in the literature. To adumbrate the conclusion: as interesting as the Joseph et al. (1997) results may be, there is reason to believe that the attentional blink paradigm may not provide a suitable method for determining whether feature detection requires attention. At the very least, it is premature to take their conclusion as the last word.

SOME PROBLEMS WITH THE ATTENTIONAL-BLINK PARADIGM

Let me first introduce some dissonance at the empirical level. Egeth, Leonard, and Palomares (2008) examined how subitizing (the ability to estimate small numbers) was affected by a dual-task requirement. In experiments modeled after the Joseph, Chun, and Nakayama (1997) study, subjects had to identify a letter within an RSVP stream and then indicate the number of green dots presented on an imaginary circle around fixation. The number of dots ranged from 0 to 9. There was a marked attentional blink, as in Joseph and colleagues (1997), for all numerosities from 2 to 9. However, performance was independent of lag for 0 and 1 dot. Were these conditions just too easy to show an attentional blink effect? Additional studies suggest not. The same result was obtained in a second experiment, with greatly reduced luminance values, and in a third experiment, in which subjects had to count green dots in displays that also contained white dots. Note that for trials with 0 or 1 green dot, this latter condition is similar to that of Joseph and colleagues (1997), but the results are drastically different. Leonard (2008) has explored the differences between these two studies and found some important clues, including an important role for top-down guidance, but the mystery is not yet completely solved. (For a discussion of the roles of practice and task difficulty in the Joseph, et al. 1997 study, see Braun, 1998, and Joseph, Chun, & Nakayama, 1998.)

As described earlier, the attentional blink is usually assessed at positive lags. In the case of Joseph et al. (1997), an attention-demanding letter-identification task preceded a putatively preattentive orientation-discrimination task. What would happen at negative lags, with the feature-detection task first followed by the letter-identification task? Nakama and Egeth (described in Egeth, Folk, Leber, Nakama, and Hendel, 2001) ran such an experiment. When the display containing the orientation target came first in the stream, there was still a large decrement in the ability to detect an orientation target, under conditions in which the subjects had to attend to the RSVP stream compared to when they did not. This suggests that the dual-task decrement in detecting an orientation singleton was not caused solely by the process of identifying the target letter. It appears that merely preparing for the identification of a potential target letter is attentionally demanding. Recent theoretical efforts to account for the attentional blink go further in the direction of arguing that it isn't really about temporarily depleted resources at all, but instead reflects the time course of an attentional gating system that enhances relevant and suppresses irrelevant information (Olivers & Meeter, 2008)

In sum, it is not at all clear that feature-search results under RSVP conditions question the automaticity of feature coding. Until the ambiguities concerning attentional resources and dual-task methods in general are resolved, the results from these methods cannot be used to argue against an automaticity account.

TOP-DOWN EFFECTS AND AUTOMATICITY

Another criterion that has been used in assessing automaticity is independence from top-down control. To what extent does feature detection exhibit such independence?

Hubel and Wiesel (1968), among many others, displayed stimuli to anesthetized animals and found vigorous responses in various areas of the cortex. From this observation alone we know that, in some sense, basic features are coded automatically. However, this sort of coding is not necessarily what is at issue in a cognitive approach such as feature-integration theory, as it doesn't eventuate in behavior. We can look instead to the study of awake, behaving organisms, and ask if top-down variables modulate sensory coding. What we find is a large number of studies suggesting that such modulation is commonplace.

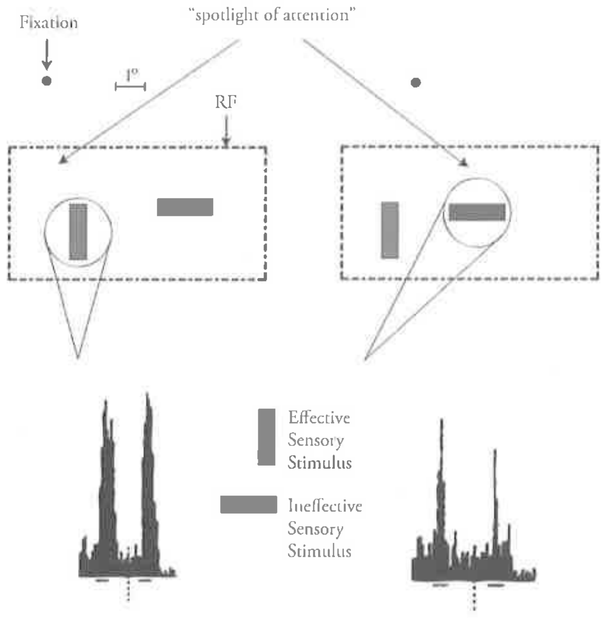

Figure 7.2 Effects of selective attention on the responses of a neuron in extrastriate area V4. Two stimuli are presented simultaneously within the receptive field of a neuron (represented here by the dashed outline rectangle). When presented individually, one of the stimuli, in this case the green horizontal bar, is an effective stimulus for this neuron; the other stimulus, the red vertical bar, is ineffective. When the two stimuli are presented at the same time, the response of the cell depends on how attention is directed. The two panels of the figure represent two trial types. In the left panel, the eyes remain at fixation and attention has been directed to the green bar. The cell responds vigorously. In the right panel, the stimuli and the eye position are as before, but attention has been directed to the red bar. The cell responds much less vigorously. Note: The attended locations are circled here, but these circles were not present in the display. (Adapted from Desimone, Wessinger, Thomas, & Schneider, 1990.) (See color Figure 7.2.)

One well-known example is Moran and Desimone (1985), who recorded from neurons in area V4 of the monkey brain. The monkey was trained to attend to one of two objects that could be presented within the receptive field of a V4 neuron. The two objects were selected such that one of them, when presented alone, evoked a strong response from the neuron, while the other, when it was presented alone, evoked a weak response (See figure 7.2). These were referred to as the effective and ineffective stimuli, respectively.

When both stimuli were present at the same time within the receptive field of a single neuron, the neuron's response was stronger when the monkey attended to the effective stimulus than when it attended to the ineffective stimulus. In other words, an effective stimulus present in a cell's receptive field did not evoke much of a response as long as the monkey was attending to an ineffective stimulus. There are many other similar findings in extrastriate cortex, and, by now, there have been several successful demonstrations of top-down modulation of response in area V1 (e.g., Ito & Gilbert, 1999; Motter, 1993; see Posner & Gilbert, 1999 for a brief review). Thus, single-unit recordings in animals have clearly shown modulation of early visual signals by top-down mechanisms.

Turning to studies of humans, there are several fMRI studies that show that attention selectively affects neural activity. To cite just one, O'Craven, Rosen, Kwong, Treisman, and Savoy (1997) measured activity in the MT-MST complex, which is sensitive to stimulus motion. They used displays consisting of numerous white and black dots that were either stationary or moving (the white dots all moved or stopped as a set, as did the black dots). They found more activity when subjects attended to the moving dots than when they attended to the stationary dots, even though the visual stimulus was the same during the two conditions.

There is ~~also~~ some strictly behavioral evidence that speaks to this question as well. For example, Most, Scholl, Clifford, and Simons (2005) examined the extent to which unexpected stimuli were noticed by subjects when they were engaged in a demanding visual task. For example, in their first experiment, there were eight haphazardly moving objects on the screen, four circles and four squares (two of each shape were white and two were black). In one condition, subjects had to count the number of times objects of a given shape bounced off the sides of the display, while in another condition they had to count the number of times objects of a given color bounced off the sides of the display. Subjects in each condition had two trials as just described. On the third, critical trial a ninth object, a black circle, was introduced and moved across the middle of the screen from one side to the other over a period of five seconds. When subjects were counting bounces of black objects (circles and squares) they detected 88 percent of the unexpected black circles; when they were counting bounces of white objects (circles and squares) they detected 0 percent of the unexpected black circles. The effect was similarly strong when subjects were attending to shape. They detected 81 percent of the unexpected black circle when they were counting bounces of circles, but just 6 percent when they were counting bounces of squares. In sum, they found that the probability that a person will notice an unexpected object depends strongly on his or her top-down attentional set.

CAN FEATURES BE DETECTED WITHOUT FOCUSED ATTENTION?

We have already seen that elemental features can be coded spatially in parallel. Note however, that Treisman also argued (e.g., 1988, p. 203) that they are coded without spatial attention. These are related concepts, but they are not identical. For one thing, attention was not manipulated in the studies demonstrating spatial parallelism. In some given region of visual space (say the screen of a monitor), features may be coded spatially. Would this coding be the same regardless of whether attention were directed to the screen or not? We have already seen an effect of spatial attention in the Moran and Desimone (1985) study; we focus here on studies of human perceptual processing.

ATTENTIONAL CUING EXPERIMENTS

Treisman (1985; discussed also in 1988) attempted to directly test the assumption that attention is required for the accurate conjunction of separable features, but not for the perception of the features themselves. Eight objects were displayed briefly on the perimeter of an imaginary circle. These objects differed in shape, size, color, and whether they were filled or solid (See figure 7.3). The location of the target was precued by flashing a bar marker 100 milliseconds before the onset of the display.

The bar marker was presented on most trials, and when it was presented, it was 75 percent valid; that is, it pointed at the correct location 75 percent of the time, and the wrong location 25 percent of the time. Two conditions were compared: in one, the target was defined by a feature (e.g., "red"); in the other, targets were defined by a conjunction of features (e.g., "large brown outline triangle"). For the conjunction targets there was a substantial validity effect; performance was better on valid than invalid trials. For the feature targets there was little effect of validity. (It is not reported whether that small effect was statistically significant.)

Prinzmetal, Presti, and Posner (1986) conducted a somewhat similar experiment (see Prinzmetal, 2012; chapter 9 in this book). They also found a much larger effect of spatial cuing on the report of conjunction stimuli than of feature stimuli, but both effects were significant. This suggests that, "...orienting attention to the location of the cue affects the quality of the perceptual representation for features and their integration" (p. 361).

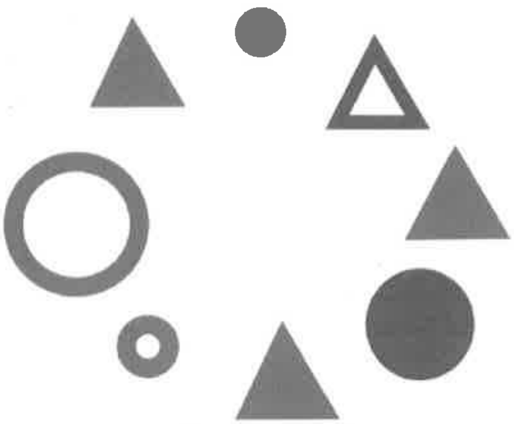

Figure 7.3 An example of a stimulus display from Treisman (1985). Stimuli varied in shape, size, color, and whether they were filled or outline. The location at which the target would occur, if it was present, was precued by flashing a pointer to that location 100 milliseconds before the display was presented. The precue correctly predicted where the target would be on 75 percent of the trials. On the other 25 percent of the trials, the target appeared somewhere other than at the cued location. (See color Figure 7.3.)

A different and perhaps more straightforward cuing experiment was conducted by Theeuwes, Kramer, and Atchley (1999). They examined the effect of attention allocation on feature search. Their results suggested to the authors that the function of attention is not so much to enhance processing in one region as it is to inhibit processing in another region. On each trial, the stimulus display consisted of two arrays of bars that were presented simultaneously, one distinctly to the left of fixation and one distinctly to the right of fixation (See figure 7.4). The task was to determine whether the display contained one bar that was red, or whether they were all gray. Total display numerosity was either 30 or 50; with half the bars allocated to each array. In their first experiment, attention was manipulated by means of the presentation of a cue that consisted of a gray box that encompassed one or the other of the two arrays or both arrays (neutral trials).

Cue validity was 80 percent. Mean RT did not differ between display sizes of 30 and 50 and thus the data conformed to the pattern observed by Treisman and Gelade (1980) and others for detection of a color singleton. Valid trials were slightly but not significantly faster than neutral trials, but invalid trials were much slower than neutral trials. In a second experiment, cue validity was reduced to 50 percent . The results were essentially the same as before: no benefit from a valid cue, but a significant cost from an invalid cue.

These results seem entirely reasonable, but it is worth spending some time contemplating what they mean. First, we shall assume that the sudden onset of gray box(es) captures attention at least briefly. Moreover, given what we know about object-based attention, it seems reasonable to think that

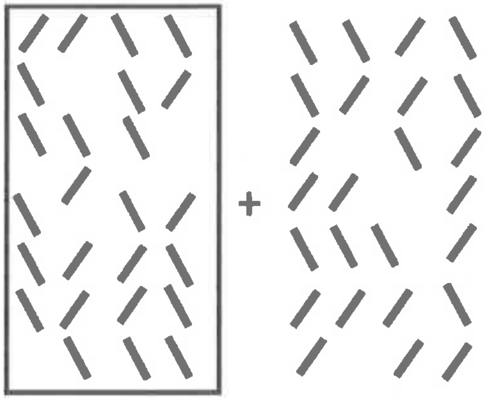

Figure 7.4 Sample of a stimulus display of size 50. Subjects had to detect whether a red line segment was present. The outline rectangle served as a cue and indicated with 80 percent validity the stimulus array in which the red line segment would be presented. (Adapted from Theeuwes, Kramer, & Atchley, 1999). (See color Figure 7.4.)

attention will be attracted not just to the gray outline itself but to material within that space (e.g., Egly, Driver, & Rafal, 1994). Let us consider the lack of a benefit for the valid cue in the Theeuwes et al. experiments. Here, attention has been drawn to a region containing half the display elements, and yet performance is no better than in the neutral condition where attention is spread over the full number of display elements. This result supports a conclusion based on the display size manipulation that there is no capacity limit evident in this experiment. Second, the large cost when attention is drawn to the invalid location confirms that attention has been drawn to the cued space. When subjects fail to find the target, they redirect attention to the other side of fixation and search there. Thus, when attention is directed to one object (one gray box and its contents), processing is retarded in a simultaneously presented object. This amounts to a demonstration of object-based attention in which features within an object are coded faster than those outside that object.

There is an interesting similarity between the pattern of results observed by Theeuwes et al. (1999) and the pattern of results observed by Robertson and Brooks (2006) in a study that used the visual-search paradigm with a patient suffering from unilateral neglect of the left visual field. For the patient, featural pop-out occurred in both visual fields, but was slower in the neglected field (see also Esterman, McGlinchey-Berroth, & Milberg, 2000).

USING SECONDARY OR IMPLICIT MEASURES TO ASSESS ATTENTIONAL INVOLVEMENT

Another approach has been to let subjects search for a target defined by a feature, and then try to find evidence that focal attention has, or has not been involved. Examples of this are studies by Theeuwes, Van der Burg, and Belopolsky (2008), Egeth and Moher (2009), and Luck and Ford (1998).

The study by Theeuwes, et al. (2008) made clever use of a priming paradigm. The stimuli were letters presented on an imaginary circle surrounding fixation. Subjects simply indicated if a red character was present. There was either zero or one red letter among otherwise all gray letters on each trial. The investigators were interested in whether there would be intertrial priming effects when the target letter was repeated. For example, if the red letter happened to be an E on consecutive trials, would participants be faster to respond on the second trial even though the identity of the letter was task irrelevant? If priming occurred, this would indicate that participants identified the letter, not just its color. On the assumption that letter identification cannot be accomplished preattentively, priming would thus indicate that attentional resources had been directed to the target. There was also a character (a digit degraded by masking dots) present at fixation. In the single-task condition it could be ignored, but in the dual-task condition it had to be reported along with the presence or absence of a red character. The data indicated that intertrial priming was present in both the single- and dual-task conditions, suggesting that even when a difficult central task was added, participants were still directing attention to the target stimulus. The dual-task data are important because the attentional shift may have occurred in the single-task condition because the task was easy and, thus, "excess" attentional resources were available (cf. Lavie, 1995). This pattern of results suggests that focal attention may be required for the detection of a salient singleton.

One might wonder whether the crucial assumption that identification of the target letter requires focal attention is correct. If all of the letters were processed in parallel, then priming might also have been expected—even for the nonsingleton gray letters. This was addressed in a control experiment in which repetition priming for singleton and nonsingleton letters was compared. The result was that only the red singleton letters produced repetition priming. The Theeuwes et al. (2008) study is interesting; however, in placing it in context, several issues need to be considered. First, although the main result is taken to be contrary to FIT, it is worth pointing out that Treisman and Gormican (1988, p. 39) wrote: "Feature analysis seems to take place automatically on many perceptual dimensions; we normally become aware of the color and length of lines when discriminating their orientation and of the size and shape of the dots when discriminating their contrast." It is definitely a step, although perhaps not a large one, to adding "become aware of its form when detecting its color." (It's a step because the form of a letter is not an elemental feature dimension.)

It is also worth pointing out that the red letter is a salient singleton and subjects had to detect its presence among all gray objects. Given Theeuwes's earlier research (e.g., 1991, 1992) it would not be at all surprising if it were to capture attention in the circumstances of the 2008 paper (cf. Bacon & Egeth, 1994; Leber & Egeth, 2006). And if it were to capture attention, it is reasonable to think that the identity of the letter would be encoded, because alphanumeric characters may be subject to "compulsive encoding" (Teichner & Krebs, 1974; see also Stroop, 1935, McLeod, 1991). The results may reflect the special circumstances of the experimental design rather than the general principle that attention is required to detect the critical feature of the target (in this case its redness).

The Theeuwes et al. (2008) study is quite provocative. One would like to know what the results would be like if the conditions of the experiment were designed to avoid attentional capture. Feature-integration theory does not require that this test have the target consistently be a red item in a background of gray items. One could just as well have subjects indicate if a red item is present when the other elements in the display are a variety of different colors. This would put subjects into feature-search mode as opposed to singleton-detection mode (e.g., Bacon & Egeth, 1994). If Theeuwes et al. (2008) are correct in their assertion then priming should obtain again. Egeth & Moher (2009) have reported the results of such an experiment. There was no priming at all. It would appear that focal attention is not required for the detection of an elemental feature.

Another approach to this issue was taken by Luck and Ford (1998) whose data support Treisman's conjecture that feature detection does not require focal attention.

Luck and Ford (1998) had subjects identify whether a specific color was present in a display. The display consisted of 12 haphazardly positioned squares, half in the left visual field and half in the right. In each visual field,5 of the squares were gray and one was colored. Thus, a display might have consisted of 10 gray squares, with 1 red square along with 5 gray squares on the left, and 1 green square along with 5 gray squares on the right. Electroencephalography was used to record the electrical activity of the brain. The subjects' task was to indicate whether a specific color was present in the display. For the display just described, the subject might have been asked if red was present. The authors were interested in the N2pc, an event-related potential (ERP) component that is thought to occur when subjects direct attention to a location in space. An N2pc was observed in this task, contralateral to the target, suggesting that attention had to be directed to the target in order for it to be identified.

As in the Theeuwes et al. (2008) study, the attentional shift may have occurred because the task was too easy. What would happen if attention were more fully occupied? In a second condition, subjects were required to identify a target letter (partially obscured by masking dots) that appeared at fixation in addition to indicating whether a red character was present. When this second task was also required, the N2pc was no longer observed, even though the subjects' accuracy at identifying the color in the primary task remained the same as before. These data suggest that attention is not required for identification of a feature like color.

SUMMARY

With respect to the three key properties of feature detection described by Treisman, we can reach the following conclusions. (1) Visual search studies with shallow to zero slopes suggest that feature detection can be carried out in parallel across the visual field. Even visual search studies with steeper slopes do not require the assumption of limited capacity. (2) There is reason to doubt the automaticity of feature detection. The strongest basis for doubt is the substantial evidence of top-down modulation of sensory processing. Another test of automaticity has been to check for independence of processing from a concurrent task. The results here are much less clear. In particular, the attentional blink studies that have addressed the issue cannot be considered decisive. There is some disparity among the results, and, more important, it is not clear at this time just what the performance decrement in those studies means. (3) Finally, it is not clear yet whether feature detection does or does not require focused attention. Cuing studies suggest a benefit when subjects can focus attention in advance on spatial locations (or objects) that contain a target feature, but studies using other paradigms suggest focal attention is not necessary to detect a feature.

Thus, it would appear that more than 30 years after its enunciation, some aspects of FIT as it was originally proposed have been superceded by new data. What is more impressive is how much of the theory remains intact. More importantly, whether intact or not, what is undeniable is the enormous contribution the theory has made, and is continuing to make, to the fields of psychology, cognitive science, and neuroscience.

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