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Attending to the Spatial Frequency and Spatial Position of Near-Threshold Visual Patterns

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ABSTRACT

Results from extrinsic-uncertainty, primary-with-probes, and concurrent experiments using near-threshold visual patterns differing in spatial frequency or spatial position suggest: (a) Typical observers can attend to and give direct reports from selected ranges of spatial frequency and spatial position in the sense of basing their responses on appropriate subsets of visual mechanisms. (b) This selective attention may sometimes occur early enough to block the unmonitored mechanisms' outputs from influencing conscious perception. (c) Observers in these near-threshold tasks can also attend to the whole range without losing any information from any subpart of the range. (The largest number of far-apart spatial frequencies or spatial positions used was five or three, respectively, however.)

INTRODUCTION

Receptive-Field Model

In the current model of near-threshold pattern vision (reviewed in Graham, 1981), there are multiple mechanisms—the physiological substrate for which might be single neurons in the visual cortex. These mechanisms' receptive fields are potentially located at different places in the visual field (i.e., sensitive to different spatial positions), of different sizes and orientation (i.e., sensitive to different ranges of spatial frequency and orientation), and so on. For the quantitative prediction of near-threshold results, the following assumptions are commonly made:

1. The mechanisms' outputs are noisy or variable, with different mechanisms' outputs being probabilistically independent (uncorrelated).
2. Visual patterns of very different spatial frequency and/or spatial position (and/or orientations) are thought to excite completely disjoint subsets of these mechanisms that do not interact with one another in any way at near-threshold contrasts.
3. The observer's decision variable (in the sense of standard signal-detection theory) in detection experiments is the maximum of the outputs from all the mechanisms—for example, the observer says "yes" if and only if this maximum is greater than some criterion.
4. In simple-stimulus identification experiments—in which a stimulus containing a single value on the relevant dimension is presented on each trial and the observer's task is to say which of several possible values was presented—the observer's response is the value that corresponds to the mechanism producing the maximum output.

Monitored Mechanisms

Several aspects of this current model will undoubtedly be modified before it does a perfect job of accounting for near-threshold pattern vision although the model does an extremely good job as is. The present chapter discusses one such modification: the observer is assumed to "pay attention to" only a subset of the mechanisms in the sense that the decision in 3 or 4 above is based only on the outputs from that subset rather than of all the outputs. The mechanisms in that subset are said to be "monitored." Note that, for the present, very little is implied about the stage at which this selective attention occurs.

EXTRINSIC-UNCERTAINTY EFFECTS

Detection and identification performances are worse when an observer is uncertain about the spatial frequency or spatial position of a simple visual pattern—because trials of several different values are randomly intermixed (uncued intermixed condition)—than when he or she is certain because only trials of that one stimulus can occur on each block (alone condition). No such extrinsic-uncertainty effect occurs for intermixing contrasts, however, at least not within the range possible in detection experiments.

Although over several sessions a particular observer may seem to show a larger uncertainty effect at one spatial frequency than another, overall no consistent effect of spatial frequency is found in the range we have tested (from .67 to 18 c/deg with occasional excursions higher).

These extrinsic-uncertainty effects cannot be explained by assumptions 1 through 4 just described, but they can be explained quantitatively with the following additions:

5. The subsets monitored in the alone conditions for stimuli containing very far-apart values (e.g., grating patches of very different spatial frequencies) contain no mechanisms in common.
6. In an intermixed condition, when an observer knows that any one of several stimuli might be presented, he or she monitors the union of the subsets monitored in alone conditions for those several stimuli.

With these modifications, the observer should do worse in intermixed conditions than in alone conditions because, in the intermixed, he or she must monitor more probabilistically independent mechanisms that add noise or "false alarms" (as they are not sensitive to the stimulus on any particular trial). Note that this predicted performance decrement is entirely attributed to probabilistically independent noise sources and does NOT arise from an inability to monitor many mechanisms nor from any degradation of a mechanism's output when other mechanisms are monitored along with it. The decrement might better be viewed as an increment, therefore; the observer's performance is predicted to be better in the alone than in the intermixed conditions because he or she is able to selectively monitor appropriate mechanisms and thus avoid many false alarms.

The magnitude of the uncertainty effects in the detection of patterns of different spatial frequency and spatial position turn out to be quantitatively consistent with the preceding assumptions (necessarily elaborated to include reasonable probability distributions, a necessity that does not arise for the concurrent experiments of the next section; see Sperling, 1984, for further discussion of this point).

References for the previous statements about spatial frequency include: Davis, Kramer, and Graham, 1983; Graham, Robson, and Nachmias, 1978; Kramer, 1984; Shaw, 1984; Yager, Kramer, Shaw, and Graham, 1984. References for spatial position and contrast include Davis et al., 1983, and others' work—for example, Cohn and Lasley, 1974. Some individual differences are discussed in Yager et al., 1984.

Intrinsic Uncertainty

Although considerable flexibility in monitoring is assumed by assumptions 5 and 6, perfect monitoring is not. In fact, the subset monitored for any simple stimulus may contain not only informative mechanisms (those sensitive to the stimulus—

for example, mechanisms at the correct spatial position, spatial frequency, and orientation for a grating patch) but also noninformative mechanisms. Incorporating such intrinsic uncertainty, in fact, allows prediction of several additional features of detection data beyond those mentioned here (Nachmias & Kocher, 1970; Pelli, 1981).

Compound Stimuli

Recently we measured the detectability of compound gratings containing two spatial frequencies and of the components by themselves in an alone condition (where trials of only one pattern appeared in a given block) and in an intermixed condition (where trials of the components and the compound were randomly intermixed). The compound was very slightly less detectable in the intermixed condition than when it was alone. Because the same mechanisms are likely to be monitored both in the intermixed condition and in the condition when the compound is alone, this small uncertainty effect is puzzling. It may result from a switch between the maximum-output rule (assumption 3) in the intermixed condition and an analogous sum-of-outputs rule in the compound-alone condition (Kramer, 1984).

Effects of Auditory Cues

Auditory precues eliminate these extrinsic-uncertainty effects—producing equivalent detection performance in intermixed and alone conditions—if the cues come 500 to 750 milliseconds (msec) before the first interval in a two-interval forced-choice trial (Davis et al., 1983; Kramer, 1984). (Observers report that precued intermixed stimuli are more salient than alone stimuli; this suggests that nonasymptotic measures of performance—e.g., speeded measures—might have shown better performance in precued conditions than in alone. Percent correct detection is, however, equal in the two conditions.)

As the time of the cue is moved later in the trial, the improvement produced (relative to the uncued intermixed condition) decreases, although some remains even for cues 500 msec after the end of the second interval (Kramer, 1984—for intermixed spatial frequencies).

Direction of Motion

Somewhat oddly, the extrinsic-uncertainty effects are larger and the efficacy of cues in reducing them less for different directions of motion than for different spatial frequencies or spatial positions (e.g., Ball & Sekuler, 1981). Perhaps the eye-movement system is implicated.

CONCURRENT EXPERIMENTS

If monitoring is as flexible as assumed previously (assumptions 4 and 5) and if mechanisms' outputs are distinguishable upstream (assumptions 4, 5, and 6), then an observer might be able to simultaneously attend to two spatial frequencies or two spatial positions in a compound pattern and report on each one individually without loss (further assuming memory load and response competition are negligible).

Suppose, for example, we present the observer with: a blank, a low spatial frequency by itself, a high spatial frequency by itself, or both. Suppose we ask him or her two questions: (a) Is the low spatial frequency present? (b) Is the high spatial frequency present? The answer to each question might be a simple yes or no or it might be a confidence rating. We can formalize the first paragraph's argument as:

7. The decision variable used to answer the question about a particular component in a concurrent experiment (e.g., a particular spatial frequency) is the maximum of the outputs from all the mechanisms sensitive to that component.

To compare the model's predictions to results, compute a *d'* value for each of the two questions and for each of the nonblank patterns by comparing—in the ordinary fashion of signal-detection theory—the answers to that particular question on nonblank pattern trials with the answers on blank trials. For example, for the low-frequency question and the high-frequency-alone stimulus, the *d'* value would be calculated as follows: The probability of saying "yes, the low frequen-

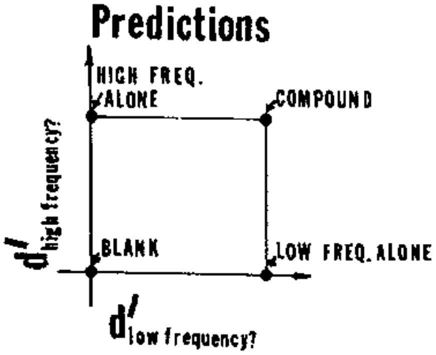

FIG. 14.1. Predicted results from concurrent experiments.

cy is present" in response to the high-frequency-alone stimulus is the hit rate, and the probability of "yes, the low frequency is present" in response to the blank is the false-alarm rate; then the false-alarm and hit rates are converted to standard normal deviates (z scores) and subtracted to get the *d'* value.

Figure 14.1 shows the predicted *d'* from one question plotted against the predicted *d'* from the other. The predicted results are a rectangle of points with that for the blank stimulus at the origin, that for the compound stimulus in the upper right, and those for the simple component stimuli at the other corners (Nachmias, 1974).

Also, because the independent mechanisms' outputs are assumed probabilistically independent, the correlation between the answers to the two questions across repetitions of the same stimulus (henceforth called an interresponse correlation) is predicted to be zero.

Spatial Frequency

Results for an experiment using far-apart spatial frequencies (2.5 and 7.5 c/deg) are shown in Fig. 14.2 for separate replications (different symbols) at several levels of contrast (from Haber, 1976; see details in appendix here). Also, the interresponse correlations were small and scattered around zero except that, for the blank stimulus, positive correlations were regularly observed (median around .2 in this study). Note that the small size of the interresponse correlations means that the *d'* value for one question will be much the same whether conditionalized on a yes to the other question, conditionalized on a no to the other question, or unconditionalized (as here).

The results in Fig. 14.2 are for long (760 msec) presentations of the gratings. Even with presentations as short as 20 msec, however, the results are the same (unpublished data from two sessions with observer LH run at the same time and using the same procedures as the results at longer durations reported in Hirsch, Hylton, & Graham, 1982).

In summary, the results for far-apart spatial frequencies are approximately as predicted. (See also Nachmias, 1974; Hirsch, 1977; Hirsch et al., 1982; Olzak, 1981).

Spatial Position

To my knowledge, there have been three concurrent experiments on the spatial-position dimension using: three far-apart spots (Wickelgren, 1967); two far-apart lines (unpublished experiment by Nachmias, 1966; details in appendix here); two adjacent but wide patches of a medium spatial-frequency (5 c/deg) grating (Kramer, 1978; details in appendix here). The durations in these three studies were all quite short (7 msec to 125 msec).

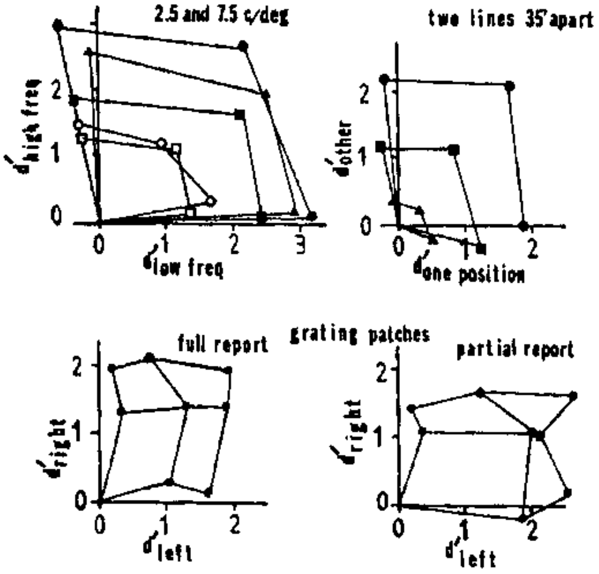

FIG. 14.2. Results from concurrent experiments on the spatial-frequency dimension (upper left from Haber, 1976) and on the spatial-position dimension (upper right, unpublished results from Nachmias, 1966; lower panels from Kramer, 1978).

The three spatial-position studies produced results for far-apart positions very like those predicted—that is, approximate rectangles on *d'* versus *d'* plots and little correlation between two responses. Figure 14.2, upper right, shows three replications (at different contrast levels) for two thin lines separated by 35 minutes of visual angle (from Nachmias, 1966). The lower part of Fig. 14.2 shows two sets of results for adjacent grating patches (from Kramer, 1978). Here nine stimuli—three contrast levels at each of the two positions—were used so the predicted results form a rectilinear 3 × 3 array.

Suppose an observer is unable to monitor mechanisms sensitive to both components simultaneously (violating assumption 6) or is unable to answer two questions each trial as well as one (violating assumption 7 because of response competition or memory load, for example). An observer would then perform better when only asked about one component each trial (single-question or partial-report or focused-attention condition; bottom right in Fig. 14.2) than when asked about both (two-question or full-report or divided-attention condition;

bottom left in Fig. 14.2). In fact, however, performance in the two-question condition is not generally worse than in the single-question condition, providing further evidence that the observer can monitor mechanisms for both components simultaneously without loss (and also give direct reports about both simultaneously).

Slight Deviations from Predictions—Interactive Mechanisms or Modified Higher Processing?

Although the results of concurrent experiments are much as predicted, small but systematic deviations of three kinds have been observed: The left and/or bottom edges of the nominal rectangle may lean inward ("confusion") or outward (a "negative influence" of one component on the other). Second, the upper right data point (the d' values for the compound) is often inside the parallogram calculated by adding the d' values for the simple components. Third, as mentioned previously, the interresponse correlations are sometimes not zero.

One class of explanation for these small deviations postulates interactions among the mechanisms themselves: inhibition (or excitation) to account for negative influences (or confusion) and shared noise sources to account for interresponse correlations (Hirsch et al., 1982; Nachmias, 1974; Olzak, 1981).

Another class of explanation elaborates the assumptions (5, 6, and 7) about further processing of the mechansims' outputs. Perhaps, for example, the signal-detection criterion to which a decision variable is compared is not constant over trials but changes depending on the values of both decision variables. Or perhaps—due to intrinsic uncertainty—some of the same mechanisms are contributing to the decision variables for both of two far-apart simple stimuli. Or perhaps the observer's response is not based on anything as simple as the maximally responding mechanism in a subset; instead, perhaps, some rather complicated function from the full set of all mechanism's outputs is calculated (as an optimal observer would do; for discussions of optimality, see Sperling & Dosher, in press; Watson, 1983).

Basis for Selection

The basis for selective monitoring when expecting a certain simple stimulus—as in the extrinsic-uncertainty experiments—need not be the same as when trying to extract information about one simple stimulus from the ongoing perception of several—as in the compound stimulus trials of these concurrent experiments (e.g., Kahneman & Treisman, 1984). The satisfactory predictions here for both experiments' results, however, suggest that in this situation the basis is the same or very similar. This basis might be said to be the component spatial frequencies or spatial positions. More precisely, it is the subsets of mechanisms corresponding to (having receptive fields that are sensitive to) these component stimuli.

Similarly, the successful predictions suggest that the basis for attending to a compound stimulus is its component spatial frequencies or spatial positions (more precisely, the union of the subsets corresponding to these components; see assumption 6). Some modification of this last statement may prove necessary to account for the extrinsic-uncertainty effect for the compound grating, however. Although interpreted above as the effect of a simple change in decision rule, this effect could also result from the intrusion either of a broad bandwidth mechanism (which is more sensitive to the compound than to either component) or of some higher-order entity specialized for the compound (a "node" or an "object file"; e.g., Kahneman & Treisman, 1984). At present, all these interpretations are equally unsupported.

HEARSAY EVIDENCE

Conscious Rejection

The results so far reported have little bearing on whether the selective monitoring occurs early, late, or sideways in some hypothetical processing. Very late (postconscious) selection might seem to be suggested by three of these results, however:

1. The small size of the extrinsic-uncertainty effects suggests that an observer is perfectly able to attend simultaneously to mechanisms sensitive to several spatial frequencies or spatial positions without loss.
2. The concurrent-experiment results suggest that an observer can directly report about at least two or three spatial frequencies or spatial positions separately without loss.
3. Postcues reduce the extrinsic-uncertainty effect.

These three results might suggest the following scenario: The observer's perceptions always reflect the outputs from all mechanisms because there is no limitation to his or her capacity to attend to all of them simultaneously. (For example, in a block where he or she knows that only 9 c/deg gratings are being presented, he or she might consciously perceive something that looks like a 2 c/deg grating whenever the maximal output from the subset of mechanisms sensitive to 2 c/deg just happens to be high—in shorthand, he or she "sees" a false alarm by the 2 c/deg mechanisms.) The observer then consciously realizes that some of what is seen corresponds to stimuli that are definitely not present (e.g., the 2 c/deg false alarm) and so consciously ignores these percepts when making his or her response. In accord with this scenario of conscious rejection of false alarms, observers report that occasionally they do consciously see and then reject "wrong" percepts (percepts having the characteristics of unexpected stimuli—

e.g., at the wrong place or wrong time or wrong spatial frequency or wrong orientation).

Preconscious Selection

Observers also report, however, that such conscious rejections of "wrong" percepts are very rare. They report that, in general, they see only percepts corresponding to expected stimuli. These introspective reports suggest that—in, for example, the alone or precued intermixed conditions of extrinsic-uncertainty experiments—selective filtering is occurring early enough that the outputs of the unmonitored mechanisms do not contribute to conscious perceptions.

The following story, related to us independently by several people, supports this suggestion. While debugging a program or calibrating equipment, you try to display a grating. You keep turning up the contrast far beyond the usual value, quite bewildered by the absence of the grating. Suddenly you do see a grating: It is actually far above threshold (perhaps a log unit) but of a quite different spatial frequency than you had intended. (There is a second and unsurprising point to this story: Even when the unmonitored mechanisms are filtered out before conscious perception, a large enough output will break into consciousness.)

PRIMARY-PLUS-PROBE EXPERIMENTS

Another result, although certainly not conclusive evidence in favor of preconscious selection, lends credence to its possibility. Perhaps an observer can be coaxed into monitoring mechanisms sensitive for one spatial frequency (the primary) and then presented with other spatial frequencies (probe spatial frequencies). To this end, an unbalanced-intermixed condition was used in which most trials were of the primary spatial frequency (known to the observer beforehand) but enough were of probe frequencies to be able to estimate the probes' detectability. One interval of each two-interval forced-choice trial always contained a blank field and the other the sinusoidal grating; the observer's task was to indicate which interval contained the grating even if it was not of the primary frequency. The detectability at each spatial frequency was also measured in an alone condition.

The hoped-for tuning of the uncertainty effect was found (Davis & Graham, 1981). For example, when a primary of 4 c/deg was presented on 95% of the trials, the detectability of 4 c/deg was as high as when alone but the detectability of 1 c/deg and 16 c/deg probes went down to chance (a loss in d' of almost 2—much larger than the loss in the ordinary extrinsic-uncertainty experiments described earlier). Detectability of closer probes was decremented also, although not so completely. When two primaries were used (1 and 16 c/deg), there were two peaks in the tuning function at these two frequencies (Davis, 1981).

If the observers were following instructions—and they say they were—these results strongly suggest that observers in the unbalanced intermixed blocks did not consciously perceive (at least not as well as usual) the patterns that stimulated unmonitored mechanisms.

Although too strong a conclusion about bandwith cannot be drawn, the following can be said: The spatial-frequency dependence of uncertainty effects—in both ordinary and primary-plus-probe experiments—is consistent with the idea that the selectively monitored mechanisms are the same ones that account, for example, for the spatial-frequency bandwidth in summation or adaptation experiments (Davis & Graham, 1981; Yager et al., 1984).

PERCEPTION OF COMPLEX VISUAL STIMULI

Global–Local Studies

In visual-search studies using suprathreshold global–local stimuli—large forms made up of small forms where all forms are easily discriminable from a blank field—an observer's ability or inability to attend to different ranges of spatial frequency is sometimes discussed. Three caveats should be considered, however, before comparing the near-threshold studies discussed here and the suprathreshold visual-search (global–local) studies.

First, too hasty an identification between low versus high spatial frequencies and global versus local structure must be avoided. As shown in Fig. 14.3, information about the identity of the global form is typically present in all spatial-frequency ranges (at least when retinal inhomogeneity is ignored).

Second, comparison of asyptotic performance measures like d' to reaction times (as measured in many suprathreshold studies) must be done with great care; reaction times reflect not only asymptotic performance levels but also processing speeds and the observer's willingness to trade accuracy for speed.

Third, both alternatives of a typical suprathreshold discrimination (e.g., is the small form *E* or *H?*) overlap heavily in spatial position, spatial frequency, and orientation as well as both being far above threshold. According to the multiple-receptive-field model of pattern vision, therefore, many of the same mechanisms produce large outputs in response to both alternatives. (A potential exception to this statement is the discrimination between orientations of blobs in the interesting global–local forms constructed by Hughes, Layton, Baird, & Lester, 1984.) With such substantial overlap, any rule (like assumptions 3 and 4 earlier) that simply compares maximal outputs from subsets of mechanisms to each other or to criteria may be close to optimal for near-threshold tasks but will be very far from optimal for such suprathreshold discriminations. Presumably, therefore, our nervous systems undertake further and more complicated processing of the mechanisms' outputs in order to make the suprathreshold discriminations.

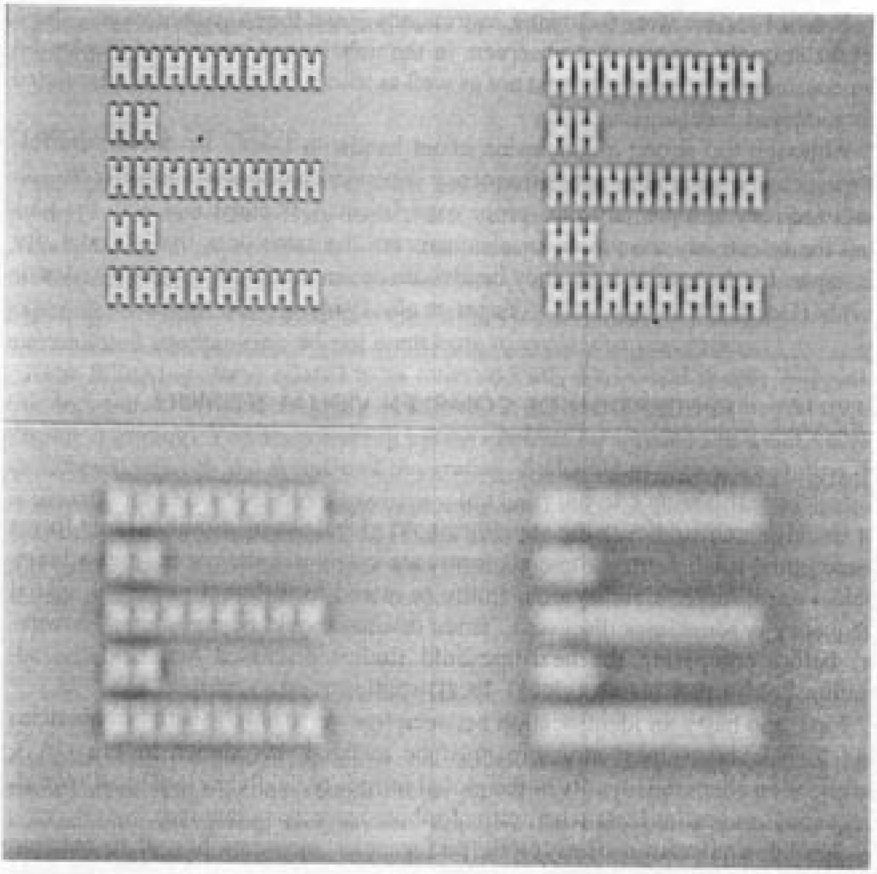

FIG. 14.3. Spatial-frequency filtered versions of an original image (not shown) in which the small *H*s were uniform white on a dark background. Upper left version contains spatial frequencies greater than 32 cycles per large *E*, upper right contains 16 to 32 cycles/*E*, lower left contains 8 to 16 cycles/*E*, and lower right contains 4 to 8 cycles/*E*. These images were provided by James R. Bergen of the RCA David Sarnoff Research Center using the LaPlacian Pyramid technique (with $a = .375$) of P. J. Burt and E. H. Adelson, IEEE Transactions on Communications, 1983, Vol. Com–31, 4, 532–540. The reproduction has undoubtedly distorted these images somewhat, but not so much as to mislead the reader.

In light of this third caveat, the conclusion that observers in the near-threshold experiments can monitor all relevant mechanisms simultaneously and without loss should not be expected to generalize to typical suprathreshold tasks. It seems entirely plausible that, in the complicated calculations required to make suprathreshold discriminations effectively, only some of the mechanisms' outputs can be dealt with simultaneously. One might even argue that preconscious selection occurs in near-threshold experiments—although the observer has the capacity to consciously reject false alarms in those tasks—only because in more ordinary situations costs are incurred if all mechanisms' outputs are allowed upstream.

Basis for Suprathreshold Selection

On the other hand, the conclusion that an observer can selectively attend to the spatial-frequency or spatial-position components of near-threshold patterns (more precisely, can monitor the corresponding subsets of mechanisms) seems more likely to generalize to suprathreshold tasks. Few would argue about selectively attending to spatial position, but selectively attending to spatial frequency or "scale" of objects—that is, to mechanisms with a given size of receptive field—is more controversial.

The objection might be raised, for example, that we do not see patches of sinusoidal gratings in complex visual scenes. However, just as component tones can be "heard out" in musical chords but not in speech, the component sinusoids in suprathreshold compound gratings can easily be "seen out" if the spatial frequencies are a factor of four or five apart. Further, although our immediate, untrained reports of perceptions are, indeed, dominated by objects or by objects at given spatial positions at given times (and experimental results demonstrate objects' importance in controlling attention—e.g., Kahneman & Treisman, 1984), the scale of objects is also quite salient in perception. You can easily decide to "look at" small details or at large structures (as in Julesz's 1980 zoom-lens analogy). Indeed, the conclusion here that either low or high spatial-frequency components of simple near-threshold patterns can be monitored with equal facility accords with the conclusion that either global or local cues in suprathreshold patterns can be attended with equal facility (Hughes et al., 1984; Ward, 1982).

Selective Attention To Avoid False Alarms

Commonly discussed adaptive functions of selective attention include the prevention of: perceptual overload, memory overload, and paralysis resulting from response competition (e.g., Kahneman & Treisman, 1984). In visual scenes of the everyday world, many important components—very high spatial frequencies at the fixation point, not so very high spatial frequencies a few degrees out—are at or below their contrast threshold, a range where noise is widely believed to limit vision. Suprathreshold vision may also be noise limited in many cases (e.g., Pelli, 1981). The avoidance of visual false alarms—which contributes to prevention of perceptual overload although little mentioned under that rubric—is, therefore, an adaptive function of selective attention that could be of considerable importance in ordinary visual perception.

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APPENDIX: CONCURRENT EXPERIMENTS

Spatial Frequency and Spatial Position of Grating Patches

Details of equipment can be found in Hirsch et al. (1982). Vertical sinusoidal gratings were presented on a CRT screen seen through an aperture in an illuminated circular surround approximately matching the screen in mean luminance and hue. In the spatial-frequency (spatial-position) experiments, the aperture was 6.2° wide by 4.75° high (5.25 × 4°) at a viewing distance of 129 cm (150 cm) at a mean luminance of 10 cd/m-squared (1.9 ft-L). The contrasts of the two components were chosen to roughly equate their detectability.

Viewing was binocular with natural pupils and normal spectacle corrections.

After each trial, the observer pushed two buttons to indicate the answers (yes or no) to the questions about whether each of the two components was present. There was two-alternative feedback (correct versus incorrect).

Spatial-Frequency Experiments (Haber, 1976). The gratings (of 2.5 and 7.5 c/deg) filled the CRT screen. There was no fixation point. The overall phase of the patterns was randomized from trial to trial to prevent the use of spatial position as a clue to identify. The relative phase in the compound was held constant throughout a session and haphazardly randomized across sessions. The stimuli were exposed for 760 msec (with abrupt onset and offset). There were 125 trials per session per stimulus (per point on the graph).

Spatial-Position Experiments (Kramer, 1978). The two simple stimuli were adjacent gratings patches each containing 13 cycles of a 5 cycle/degree grating. When both patches were present they formed a continuous grating across the display. Marks on the surround above and below the stimulus indicated the division between the two patches. The observer was instructed to fixate at this division. Each stimulus was presented for 125 msec with abrupt onsets and offsets. In each randomly ordered block of trials, there was a total of 40 presentations of each of the nine stimuli (three contrast levels including zero at each of two positions). Two blocks were run each day to constitute a session. Eight full-report sessions were run on observer TS at the same contrast levels (average results for all 640 trials per stimulus shown in lower left Fig. 14.2). Four sessions on a second observer, PK, yielded very similar results. Observer TS also ran six additional single-question (partial-report) control sessions in which she answered only one of the two questions in each session.

Variations. Several variations were tried by Haber (1976) with several observers: nine (3 × 3) stimuli, 2.5 paired with 4.2 c/deg, confidence-rating answers, answers of "blank, low, high, both" rather than answers to questions about components, four-alternative feedback (blank, low, high, both) as in Hirsch et al. (1982), and no feedback. Results were always similar to those shown, but with some variation in the extent to which the three deviations (see main text) appeared.

Improvement in discriminability across sessions was never seen with 2.5 and 7.5 c/deg although it was with 2.5 and 4.2 c/deg.

Spatial Position of Lines (Unpublished Data, Nachmias, 1966)

Two, thin parallel lines were separated by about 60, 35, or 5 minutes. At the intermediate separation, three different intensities were used (producing the three sets of results shown in the upper right of Fig. 14.2). The bright vertical test lines (about 1.5 minutes wide × 4 degrees high) were flashed for 50 msec on a large continuously present adapting field in a Maxwellian view apparatus. The display was seen monocularly in Maxwellian view through a 2 mm artificial pupil. There was a black fixation point (subtending about 10 minutes) in the center of the adapting field. One line was presented 10 minutes to the right of the fixation point. The other line was further from the fixation point. Feedback was given.

There were approximately 300 trials per stimulus (per point in the figure). The results at the largest separation were like those shown. The results for very close lines were quite different, however, showing considerable confusion between the positions (just as there is considerable confusion between close spatial frequencies; see Hirsch et al., 1982).

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