13 Background Structure

As stated in Chapter 11, there are many forms of background structure and several ways in which they can influence detectability of a target. The structure may be adjacent high contrast objects which modify thresholds due to their energy content; local background structure which interacts with the target destroying the concept of one contrast or one illuminance gradient around a contour; a local region of dissimilar luminance to the rest of the field against which to view a target; a sub-threshold structure which nevertheless interacts with threshold; a temporal structuring of the background which interacts with target interpretation; random noise or 'intelligence' structure which may change the confidence level at which a decision is made. Considerable study has been given to several of these areas. In this chapter what the author considers to be some of the more important parts of the large body of data will be summarised. It will be shown that certain of the phenomena observed may be tentatively explained by considering the retinal image gradients associated with the complex situations.

13.1 LOCAL BACKGROUND STRUCTURE

13.1.1 'Receptive Field' Studies

A class of study which has received a considerable amount of attention in recent years is concerned with the influence of symmetrical local surrounds on thresholds of simple stimuli. These studies are mostly classed 'receptive field' studies because of the belief that they illustrate the extent to which a signal in a given optic nerve fibre is influenced by incoming data from an extended portion of the retinal image. These studies involve a number of situations.

Some of the most important studies are those of Enoch[1,2] and Westheimer[3,4], where a small flash stimulus is viewed against various sizes of circular plateaux of strong local luminance superimposed on a general lower background luminance. In these experiments there is usually a differential luminance between the local surround and the general background of the order of 1 to 2 orders of magnitude. At high photopic levels the findings are that with small surrounds (of diameter less that one mrad) the threshold is, if anything, enhanced. As the plateau diameter is increased to around 1.5 mrad the thresholds degrade markedly before recovering a great deal as the plateau size is increased to 6 mrad diameter or more. For stimuli presented extra-foveally the form of threshold trend is similar, but with the point of maximum degradation moving to larger sizes. At low light levels it is found that the recovery is

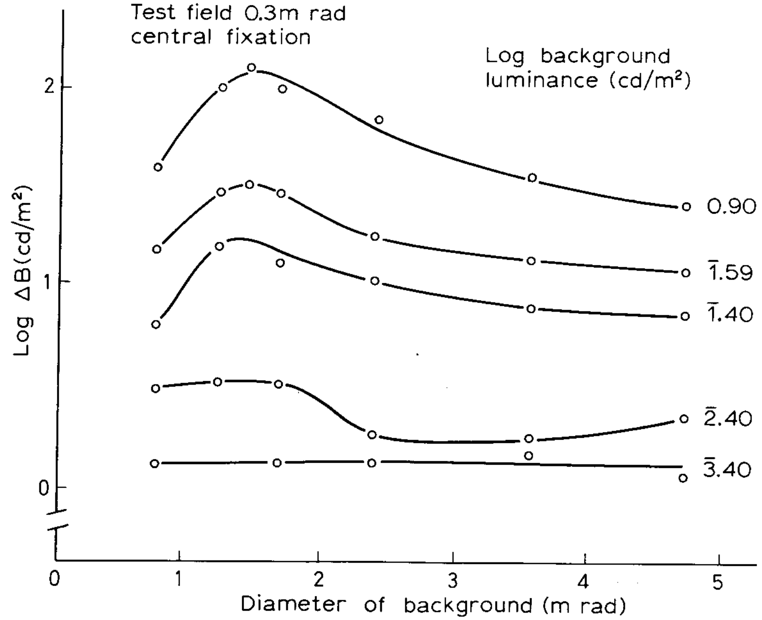
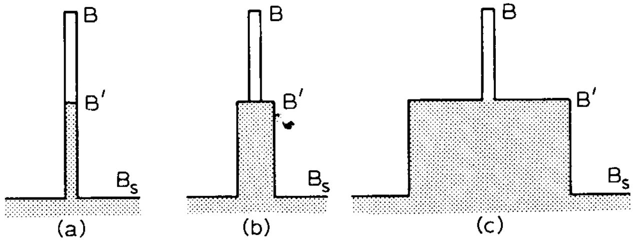


Fig. 13.1. Threshold trends for a small, flashing stimulus presented foveally at the centre of local backgrounds of various sizes and luminances. (Reproduced from Westheimer[3] by courtesy of the Journal of Physiology).

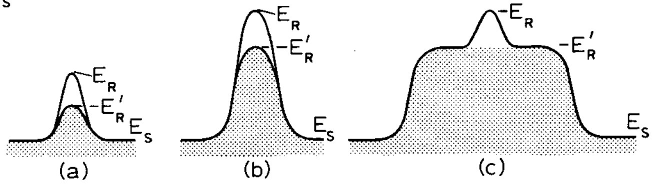
inhibited, whilst for the lowest light levels there is no measurable degradation. Sample results are shown in Fig. 13.1. The general behaviour is usually explained at high luminance as due to a local summation field of a few minutes diameter and a surrounding antagonistic or inhibitory field stretching out some 10 mrad diameter or more. It is then further argued that away from the fovea the summation and inhibitory fields expand in size, whilst at the very low luminances the inhibitory field is suppressed.

A modified explanation is believed by the author to be possible, based on the modelling of Chapters 7 and 12. Let us study the retinal images of a selection of Westheimer's stimulus presentations at high photopic luminance. In Fig. 13.2 are shown the presentation situation in sketch form for plateaux of the same size as the flash stimulus, about 1.5 mrad diameter and about 6 mrad diameter. Below is shown the equivalent retinal illuminance distribution. It will be seen that the smallest plateau (a) is unresolved on the retina, with the result that the flash stimulus merges with it, being enhanced in the process. Conversely the 1.5 mrad and 6 mrad diameter plateaux are fully resolved, so that the flash stimulus is effectively presented against an illuminance 1 to 2 log units above the general adapation level. Now the range of response of cone receptors at a given



Stimulus conditions (luminance profiles)

B = Flashing stimulus luminance, B' = Local background luminance, B_s = Surround luminance



Retinal image illuminance profiles

E_R = Flashing stimulus illuminance, E'_R = Local background illuminance, E_s = Surround illuminance

Fig. 13.2. Illustrating the retinal images for various background/stimulus combinations as studied by Westheimer[3].

adaptation level is only of the order of ± 1½ log units of luminance[5,6], the typical response function being as shown in Fig. 13.3. Thus, if the stimulus is presented on a plateau some 1 to 2 log units above adaptation level, its effective 'strength' will be reduced due to saturation effects (in much the same way as happens to grossly overexposed parts of a photograph). Hence the threshold will be degraded. This is in keeping with the results obtained by Westheimer for the 1.5 mrad plateau. As the diameter of the plateau is still further increased, it is believed by the author that there will come a time when the plateau itself effectively controls the local adaptation level due to inhibitory influences at the ganglion cell level (see Section 2.4). The threshold for stimuli presented at the centre of the plateau will then return to an unsaturated level, but will be controlled by the luminance of the plateau rather than that of the surround. This concept of control of threshold by the plateau rather than the surround is supported by recent studies reported by Esen and Novak[7]. This is believed to be an explanation for the threshold behaviour found by Westheimer for large plateaux, such experimental data as Westheimer's containing a calibration of the extent of local adaptation in the human retina – very valuable data for the study of complex fields as will be seen later. The *reason* for this local adaptation, be it photochemical (e.g. Rushton[8,9]), electrostatic[10], or due to lateral neural

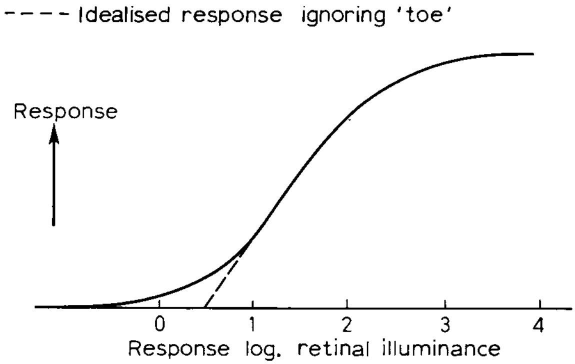


Fig. 13.3. Typical response function of a cone receptor (after Werblin[5]).

interconnections (e.g. Brindley[11]), seems unimportant to an appreciation of the behaviour of the visual system to complex, high contrast fields. The fact that there is no rise of threshold at very low luminances is believed to be due to the fact that at such low luminances the eye is fully dark adapted and the 'normal' operating point therefore moves from the centre of a response curve such as Fig. 13.3 towards the toe. Under such circumstances it would require a local difference of 3 or 4 log units of luminance to drive the local response into saturation, a condition not studied to the knowledge of the author.

If we now consider the work of Enoch[1,2], we find that his initial reported work is very much on the same lines as Westheimer's – and with the same findings. Both authors present threshold trends for other than foveal viewing, showing a maximum degradation moving to larger plateau diameters with increasing distance from the fovea, but with more sudden recovery, so that all experimental curves have fully recovered with plateaux of 12 mrad diameter and greater. This is in keeping with the known increasing separation between receptors plus a widening of the optical spread function for such off-axis situations, whilst suggesting that, over the region tested, the local adaption scaling remains substantially constant.

Other studies of Westheimer's using a 'double border' are of particular interest because it was here that he hoped, by use of a pair of adjacent 0.3 mrad wide annuli, one white and one black on a mid grey background, to show that presence of a border as such had no effect on threshold. What he did, in fact, find was that there was a very minor enhancement of threshold for 1.5 mrad and 3 mrad border diameters and a return to normal threshold for border diameters of 10 mrad and more. It is not stated in Westheimer's paper whether his borders were black inside white or white inside black, but it is believed by the author that it might make a significant difference – and that the observed results suggest he used black inside white. Figure 13.4 shows the convolutions of a 3 mrad twin border and a 0.3 mrad diameter target (as used by

Westheimer) with the spread function for a naturally focussed eye. It will be seen that the two borders largely cancel each other in amplitude but provide a very powerful border sensation since the majority of the combined transition from one to the other occurs between two receptors (> 0.2 mrad). The effect of convoluting a target with a 1.5 mrad diameter twin border is also illustrated for the two cases of black inside white and white inside black. It will be seen that the only major effect on the maximum gradient is to change the diameter at which it occurs. This might be expected to produce possible differences due to an effectively increased size in the case of white inside black.

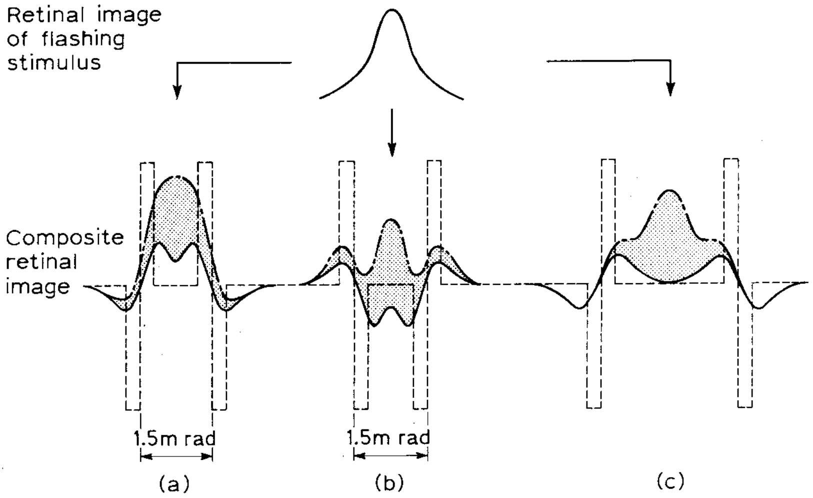


Fig. 13.4. Illustrating the combined retinal image distribution due to various Westheimer 'twin borders' and a disc stimulus, (a) 1.5 mrad diameter border, white inside black, (b) 1.5 mrad diameter border, black inside white, (c) 3 mrad diameter border, white inside black. Shaded areas indicate addition of stimulus.

Other studies of interest to receptive field considerations are those of Rentschler and Arden[12], who studied the effect of the slope of a bipartite field on the detection of an edge presented within it, and of several workers[13,16] on the threshold trends for small stimuli presented in the vicinity of a strong luminance discontinuity. These latter have regularly shown evidence of marked suppression of threshold for stimuli presented close to the edge at the high luminance side, whilst Vassilev[15] has also shown larger effects on thresholds for rectangular stimuli than for disc stimuli.

Finally Alexander[17] has recently presented some data on the effect of stimulus *size* on the form of receptive fields at scotopic levels.

13.1.2 Sub-threshold local structure

Further studies closely allied to the 'receptive field' studies are typified by those of Fiorentini and Maffei[18], who studied the effect of sub-threshold annular stimuli of varying diameter but constant area on a flash stimulus presented within the annuli. The annuli studied were all of 0.77 mrad^2 area and were all presented at 0.1 log units below their own mean thresholds. It was found that, as with Westheimer's work, for a small annulus the threshold of the flash stimulus was improved, for a moderate annulus (again 3 mrad diameter) the threshold was degraded and by the time the annulus had been increased to 6 mrad diameter the threshold had recovered to a level equal to that with no annulus present (Fig. 13.5). This time the reason for the results is believed by the author to be completely different to that for Westheimer's results. Fig. 13.6 shows the effective retinal images for flash stimuli and three annuli in the range used by Fiorentini and Maffei. The images of the flash stimulus and the respective annuli are then combined, with surprising results. It is found that the maximum

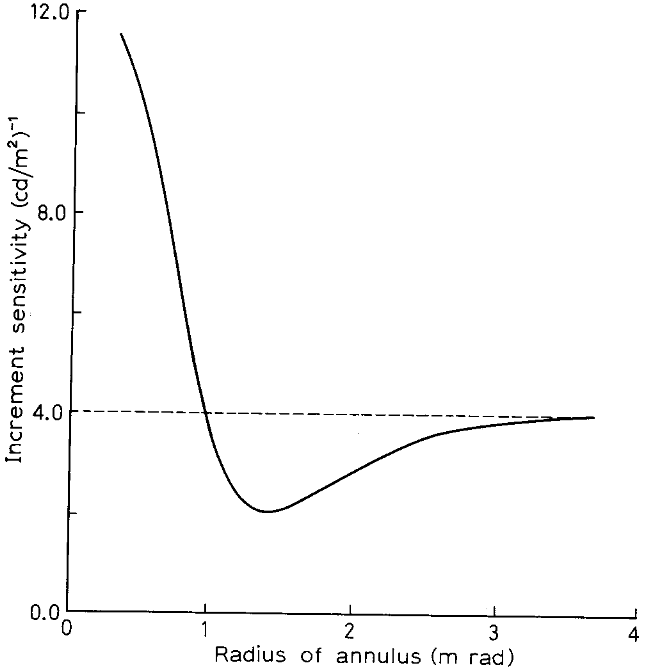


Fig. 13.5. Photopic threshold trends for a small, flashing disc stimulus in the presence of sub-threshold annuli. (Reproduced from Fiorentini and Maffei[19] *by courtesy of Pergamon Press).*

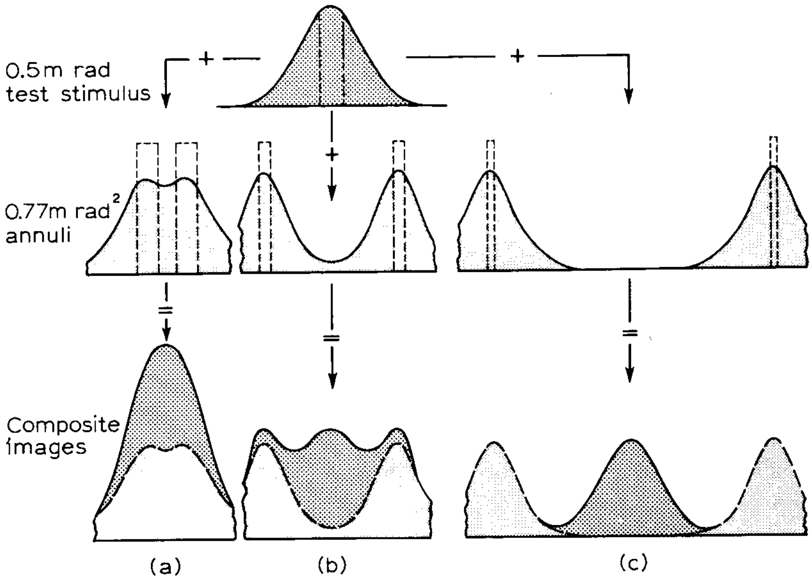


Fig. 13.6. Illustrating the superposition of retinal images of a small test stimulus and various annuli as studied by Fiorentini and Maffei[19].

illuminance *gradient* for the presentation on the smallest annulus is greatly enhanced and also that the maximum gradient region is extended. This will lead to a two-fold improvement in threshold. On the other hand, for the 3 mrad annulus it will be seen that the stimulus sinks into the annulus in such a way that the maximum gradients are reduced severely, thus raising the threshold. Finally for the 6 mrad annulus the flash stimulus fits snugly *into* the annulus, remaining virtually unmodified.

Fiorentini and Maffei also studied the effect of this second form of local structure for scotopic vision[19]. In this case their test stimulus was a 6 mrad diameter disc with various larger subliminal annuli. The findings were very similar to those for photopic vision, except that the maximum threshold degradation was no longer with annuli between 1.5 and 3 mrad diameter, but rather with annuli approaching 18 mrad diameter (Fig. 13.7). It is felt that such a set of results is closely in keeping with the differences in scale of optimal *receptor unit* spacing (i.e. spacing of groups of rods) for scotopic vision compared to photopic vision.

Other sub-threshold structure studies are those carried out by Bagrash *et al*[20], Kulikowski[21], Kulikowski and King-Smith[22] and Gelade *et al*[23]. In the first of these Bagrash *et al* studied the trend of the composite threshold of a 6 mrad diameter disc and a surrounding annulus of variable luminance. They found that

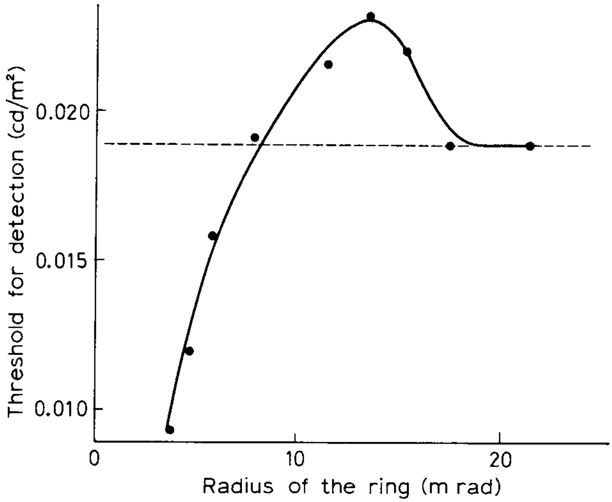


Fig. 13.7. Scotopic threshold trends for a small disc stimulus in the presence of sub-threshold annuli. (Reproduced from Fiorentini and Maffei[18] *by courtesy of the Journal of Neurophysiology).*

there was a worst threshold with the annulus luminance 50% of that of the disc, the general background being essentially dark. On the other hand, Kulikowski presented narrow dark line stimuli against sub-threshold sinusoidal patterns of 0.29 c/mrad and 1.15 c/mrad at photopic luminance levels. He found that the threshold for the line stimulus against the 0.29 c/mrad pattern was significantly altered, being degraded when presented against the bright striations of the pattern and enhanced when presented against the dark striations. Conversely he found no effect of the 1.15 c/mrad pattern on the threshold for the line. Kulikowki and King-Smith reason that these results are evidence of parallel processing in the visual system (see Section 12.4). On the contrary, the present author finds no reason to assume parallel processing as an explanation of these results. If the retinal images are generated for the various cases as shown in Fig. 13.8, it will be seen that a similar situation exists for the 0.29 c/mrad pattern as has been discussed for the Fiorentini and Maffei patterns. Conversely, for the 1.15 c/mrad pattern, the retinal image of the line spreads over more than one cycle of the pattern, there thus being little difference in the maximum gradients for the 'peak' and 'trough' superpositions. Following from this work Kulikowski and King-Smith studied thresholds for thin lines in the presence of sub-threshold lines and edges[22]. For pairs of sub-threshold lines either side of the test stimulus a characteristic summative/inhibitive response function was generated, there being a maximum threshold suppression with sub-threshold lines separated by approximately 1.75 mrad from the test stimulus (see

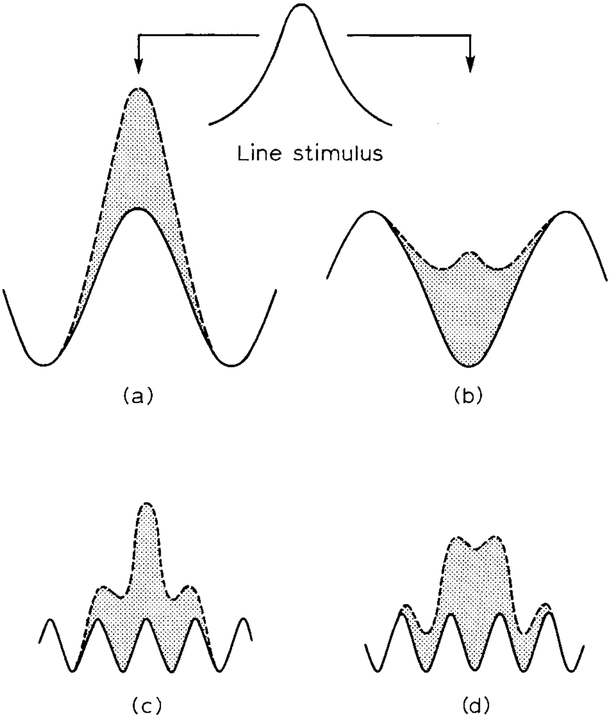


Fig. 13.8. Illustrating the superposition of retinal images of a fine line stimulus and various sub-threshold sine bar patterns, (a) superposition on peak of 0.29 c/mrad pattern, (b) superposition on trough of 0.29 c/mrad pattern, (c) superposition on peak of 1.15 c/mrad pattern, (d) superposition on trough of 1.15 c/mrad pattern.

Fig. 13.9). For edges, on the other hand, a simple suppression occured for edges close to the stimulus, the threshold recovering as the edge was moved further away. In this case the maximum degradation was with the edges approximately 0.9 mrad from the stimulus (see Fig. 13.10). Again the present author considers that the entire body of data may be potentially explained in terms of the retinal images of the complex objects and the edge gradient detection model desribed in Chapter 7.

Finally Gelade *et al*[23] have studied the effect on line thresholds of sub-threshold lines and edges at scotopic luminance levels. Their findings complement those of Fiorentini and Maffei for annuli, again showing trends very similar to those of Kulikowski and King-Smith, but on a much larger scale.

The above interpretations of receptive field and local sub-threshold structure data appear to leave little need for any *complex* neural summation and inhibition effect as supposed to exist according to Enoch *et al*[1], Westheimer[3]

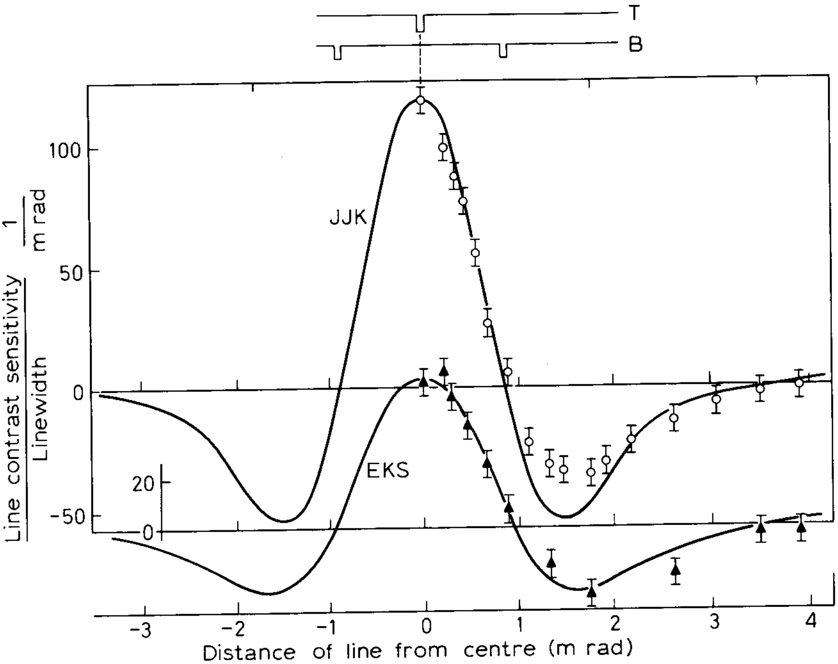


Fig. 13.9. Threshold trends for a fine line imaged between two sub-threshold lines for two observers (JJK and EKS). (Reproduced from Kulikowski and King-Smith[22] by courtesy of Pergamon Press).

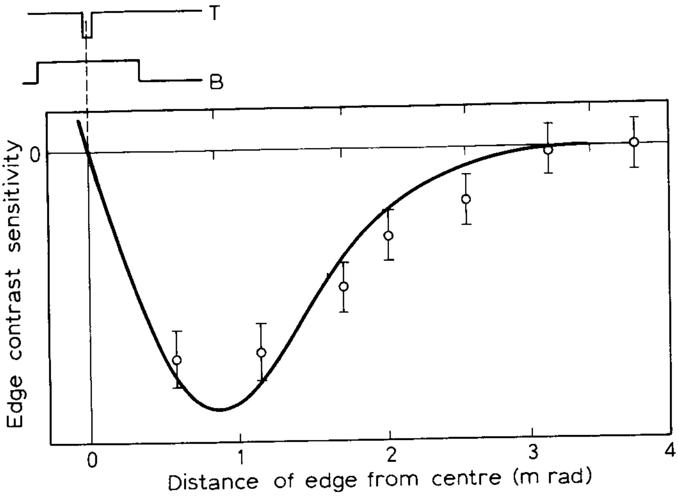


Fig. 13.10. Threshold trend for a fine line imaged adjacent to a sub-threshold edge. (Reproduced from Kulikowski and King-Smith[22] by courtesy of Pergamon Press).

and Fiorentini and Maffei[18]. All that appears necessary is to assume a simple form of progressive adaptation function in conjunction with initial examination of the complexities of the retinal image and effective neural differentiation as discussed in Chapter 7.

13.1.3 Temporal Effects

In addition to the effects described in the previous section there are other effects of local background. For instance, a short pre-exposure to a sub-threshold flash just before presentation of a stimulus can have a very similar effect to that of the spatially interacting sub-threhold line stimuli – that is, an enhancement of threshold with near overlay, a reduced effect with increased time separation and a degradation of threshold with the stimulus presented at certain critical times after the adapting flash. Examples of such studies are Fehrer and Raab[24] and Herrick[25]. Similarly the composite resultant threshold for two equal short flashes with various time separations varies in a complex manner as discussed by Clark and Blackwell[26] in particular. The information from such studies may be used to refine the temporal threshold modelling of vision, since it permits the prediction of charge and discharge time constants of the visual system more accurately than possible from the work cited in Chapter 7. However, such predictions have not been carried out at this time.

Another aspect of temporal effects is that of pre-adaptation or 'tuning'. It has been found by several workers that the threshold performance against spatial bar patterns is affected by a previous time history of viewing supra-threshold bar patterns, such changes in performance occurring whether pre-adaptation is achieved by fixation on the adapting pattern or by scanning it. For instance, Gilinsky[27] has found that pre-exposure to horizontal bars will enhance thresholds for horizontal bars and degrade thresholds for vertical bars. Pre-exposure to vertical bars has the reverse effect. Equally Tolhurst[28] has found that pre-exposure to bar-patterns of a specific frequency will inhibit subsequent threshold performance for that frequency to an extent dependent on the contrast of the adapting bars. To a lesser extent the third harmonic of a square wave has an adapting influence. Yet again Campbell and co-workers have shown that pre-exposure to a given frequency affects thresholds to a significant extent for frequencies within an octave either side of the adapting frequency[29] and that the tuning due to a pattern of a given orientation, as found by Gilinsky, is progressive – that is, there is a gradual tuning or detuning as the angle of the test pattern approaches or deviates from that of the adapting pattern[30].

Since the tuning effects discussed above are suprathreshold and due to several seconds of pre-exposure, it is considered that they cannot be retinal in origin. Instead, such effects *must* be attributed to disturbance of central processes, in contrast to the main body of 'local structure' effects discussed previously. Also, and perhaps more importantly, such temporary adaptation is not, in general, randomly variable from glimpse to glimpse and hence must be considered to be similar to learning processes or a temporary variation of a threshold signal/noise level.

13.2 GENERAL BACKGROUND STRUCTURE

13.2.1 Random Noise

Random noise can occur in a background due to many causes. Some of these, such as the noise due to photographic grain, projection screen structure and characteristic graininess of image intensifier tubes have already been mentioned (Section 9.2). Where such structure interacts with the object of interest, its main effect is to soften the boundary between object and background. Such an interaction, one might expect, would degrade thresholds for seeing the object, on the basis of the findings of Chapter 7. Van Meeteren[31] reported on several experiments using image intensifiers where such a degradation of performance was indeed observed. Fry and Enoch[32] similarly report on experiments involving controlled amounts of photographic grain and attempt to relate the effects of grain to the effects of blurring of a contour. Yet again Stromeyer and Julesz[33] and Pollehn and Roehrig[34] have studied the effects of random one-dimensional noise on detectability of a bar pattern. Stromeyer and Julesz have found that noise frequencies within an octave of the bar pattern frequency have some effect, whilst Pollehn and Roehrig find that the effects of noise are strongly dependent on bar pattern frequency distribution. Finally Rasmussen[35] has studied the effects of number of quantisation levels and contrast available in a noisy display, and has found performance to be largely insensitive to these parameters.

However, it is important to realise that the effects of random noise must be dependent on both the type of object structure and the task involved. If the task is simple detection and the object is a long border then one would expect the noise to play a minimal part, since the brain can effectively compare various parts of the border and the available 'signal' is large. Conversely, if the task is still detection but the object is small and compact, one might expect the noise to be very important. Yet again, if the task is one of recognition, the noise may be expected to hide some of the detail required for recognition, the importance of the noise then being critically dependent on the form of the detail required for recognition.

Other forms of essentially random noise are of much lower spatial frequency – such as unimportant components of a natural scene, which break up the background and possibly produce strong, large-scale interactions with the object of interest. The effect of such structure is hard to generalise upon – indeed it is likely that it must be handled for each specific case. Present knowledge only allows a very limited speculation as to the typical effect but the 'receptive field' data referred to in Section 13.1.1 should provide a lead.

13.2.2 'Intelligence' Structure

The other form of background structure which one comes across is what may be termed 'intelligence structure' – that is, other detail within the scene which is visually resolved as discrete, recognisable objects. Such structure can have a variety of effects, dependent on its relationship to the object of interest in space and in association. For instance, if one is flying over strange terrain and looking for a specific object, it is to be expected that other ground features, where they can be related to the object of interest, will be of considerable help in confirming that an otherwise meaningless patch of luminance is the object of interest. On the other hand, again in viewing the ground from the air, parts of the background may from time to time partially obscure the object of interest (screening). Yet again the presence of many objects in close proximity to the object of interest may not only upset the retinal image luminance distribution, with consequent degradation of threshold performance, but may so confuse the observer with excessive information that he is unable to isolate the object of interest from within the complex pattern. Brown[36] has chosen to call this form of complexity 'confusibility', and has reported on limited experiments carried out to investigate the effect of presence of other target-like objects on ability to recognise.

In the experiments the stimuli were scenes consisting of an array of relatively simple high contrast shapes such as that shown in Fig. 13.11. All the shapes were constructed of an assemblage of six unit squares, with a constraint that each one

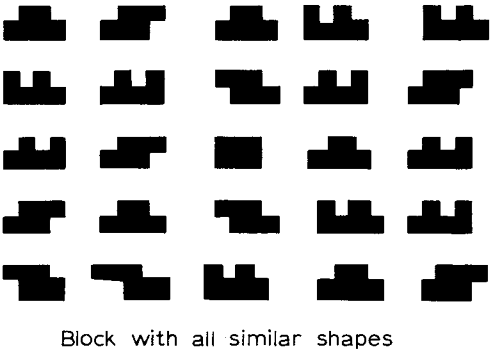


Fig. 13.11. A typical matrix of confusible shapes as used in the study of recognition in complex scenes by Brown. (Reproduced from Brown[36] by courtesy of the Advisory Group for Aerospace Research and Development of NATO).

must have a base of at least three units in a horizontal line. The shapes were arranged in groups of 25 in 5 x 5 matrices, each matrix containing one of four 'target' shapes as shown in Fig. 5.3 and as previously used in a simple recognition experiment. Two main effects were studied – packing density and the degree of similarity to the target of the other shapes used. It was found that the recognition range was significantly affected by packing density, being lower for the higher packing density. Equally the similarity of shapes to the target affected the recognition range significantly. However, when both similar and dissimilar shapes were used, their *position* in the matrix relative to the target had no effect on performance!

13.3 STRUCTURED SEARCH

The last mentioned experimental work by Brown leads us naturally into the field of structured search – that is, wide scale search for an object of interest where the background contains many objects similar to the one being searched for. The major work on this subject know to the author is that of Williams[37,38] and Howarth and Bloomfield[39,40].

Williams has investigated at considerable length the recognition of specific shapes in the presence of considerable numbers of similar shapes. In his experiments he has varied several parameters of the similar shapes – the actual shape, the contrast, the chromaticity, the size and the orientation (for irregular shapes). In his experiments he monitored his subjects' eye fixation points relative to the presented scene. He found that some 95% of all fixations fell on specific objects, the probability of next glimpse being cued to a particular object depending on its proximity to the present fixation and its similarity to the object of interest. He has produced distribution functions of probability of next fixation against difference from target in the domains previously listed. Typical distribution functions are shown in Fig. 13.12.

Howarth and Bloomfield, on the other hand, have carried out several experiments involving varying numbers of objects similar to the object of interest and have studied the *time* taken for detection. They have found that the time taken to detect is a roughly exponential function of the number of objects present and the degree of similarity. Their main experiments have involved black ball-bearings of different sizes and multisided polygons within which a single ball-bearing of equal area is to be found. Enoch[41], in work some years ago, studied the distribution of glimpses in a variety of real-life structured scenes. He found this distribution, which must be associated with performance, to vary dramatically from scene to scene (as perhaps might be expected). In many cases the glimpse distributions were rather obvious – such as a concentration along a railway track when looking for a station – but, in scenes where one might have expected there to be a symmetry in the glimpse distribution, the glimpses were found generally to be concentrated below the centre of the field being searched.

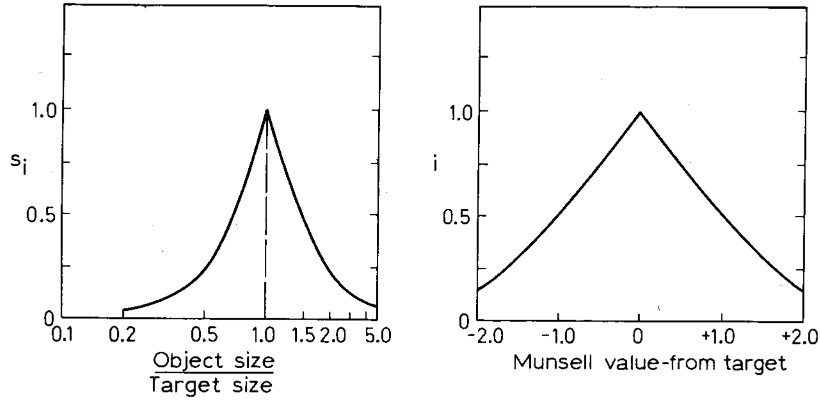


Fig. 13.12. Typical discrimination probability functions as determined by Williams for search in complex scenes. (a) as a function of similarity of size, (b) as a function of similarity of colour measured on the Munsell scale of chromaticity differences. (Reproduced from Greening[42] *by courtesy of the Advisory Group for Aerospace Research and Development of NATO).*

There was also a frequent observer bias to left or to right of the centre line. This finding, which to the present author's knowledge has been neither confirmed nor questioned by other experimentation, would appear to have some considerable importance in real-world search tasks, being presumably in some way associated with subconscious expectancy.

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