5 Recognition Thresholds

In the preceding chapter we have been concerned with laboratory performance at the most basic level of acquisition – that of detecting the *presence* of an object. By definition such detection must always imply no ability to extract detail information about an object such that it can be recognised as of a particular type. In real life it is rare indeed that the visual task involves nothing more than simple detection. Much more frequently it is necessary for an observer to recognise that an object is of the correct class – a square rather than a circle, a Landolt 'C' rather than an annulus, a given letter out of a possible set of letters, a vehicle rather than a bush. For any of these tasks it is not enough to be aware of the presence of the object – one must be able to see some of the structure. What is by no means obvious is exactly what structure it is necessary to see in order to effect recognition in a given situation. Nor is it obvious how to relate the detectability of certain local structure to the detection thresholds of isolated simple shapes. In this chapter we shall consider some of the various laboratory experiments which have been carried out to attempt to determine the thresholds associated with a variety of recognition tasks. The coverage can be by no means comprehensive owing to the enormous field covered by the term recognition. Rather we shall only summarise general statements and present some of the more clear cut threshold behavioural trends. The reader wishing to pursue this particular facet of acquisition in depth is recommended to start with Yves le Grand's book 'Form and Space Vision'[1] for general reading or Zusne's book 'Perception of Form'[2] for a study in depth. The latter reference itself contains some 2 500 references to information related to recognition – an indication of the scope of the subject.

Before proceeding to a study of various forms of recognition it is necessary to discuss a few general points about the subject of recognition. Firstly, whilst detection may be considered as a decision that a local difference in energy exists, recognition can by no means be treated so simply. Ability to recognise *must* depend, at least to some extent, on such factors as the number of possible stimuli, complexity of form, previous experience of particular forms, orientation of retinal image and association with the particular field of view in addition to the factors found to influence detection. Since the many psychological facets of recognition are beyond the scope of this book we shall in general restrict ourselves to a study of the physical aspects of recognition. However, it is impossible to separate the physical and psychological factors into watertight compartments, so some background of interactions between physical and psychological is important for the reader.

The site of the main recognition processes is variously assumed to be at the cortex – the global view of the Gestalt theorists (e.g. Marshall and Talbot[3]) – or in the vicinity of the retina (e.g. Byram[4] and Gibson[5]). The Gestalt school consider that the ease of recognition should be associated with the 'goodness' or 'simplicity' of a form, this being effectively a measure of the complexity of the shape[2]. On such a scale the circle might be considered to be the simplest form, and hence it would be expected to have the lowest recognition threshold. This has been shown to be false by a number of experimenters, several of whom have found rectangles and triangles to be more easily recognised than circles (e.g. Helson and Fehrer[6]). In contrast to the Gestalt school, Gibson has proposed that most basic processing towards recognition should be associated with peripheral rather than central processes, the main cues being difference information of various forms at the retina. He cites such factors as convergence of lines (perspective) and differential sharpness as providing cues to perception of depth and suggests that such other factors as progressive change of hue saturation and scale of texture also provide the basis for perception in 3 dimensions. Equally one is led to the concepts of differences in luminance, differences in contour direction and similar difference functions as mainly controlling recognition in 2 dimensions.

With this preamble let us now look at some of the recognition threshold data available.

5.1 SIMPLE SHAPES

The simplest form of recognition which it is possible to think of is that of recognising that a given object is one of a selected small number of simple shapes. The task might be, for instance, the recognition of a square from a set of squares, discs, rectangles and triangles. Alternatively it might be the recognition of a star shape from a set of stars and various polygons. As already stated it might be expected that in such experiments those forms with the simplest and most symmetrical outlines would be easiest to recognise. In practice the findings vary from experimenter to experimenter. Helson and Fehrer[6] and several other groups have found that, when the choice lies between rectangles, discs and triangles, amongst other forms, the rectangles are easiest to recognise with the triangles generally being next easiest. An experiment at BAC(GW)[7] using 4:1 rectangles, equilateral triangles, discs and squares of equal area and various contrasts produced similar results. In this experiment the four classes of stimuli were presented in random order at various contrasts to approximately 100 observers who were required to walk forward slowly, pausing when necessary, until they could recognise which type of object was being presented. The findings were that, on average, there was little to chose between the recognition of triangles, squares and discs of equal area and contrast, but that the 4:1 rectangles could be recognised at considerably greater ranges than the other 3 types of stimuli. An interesting subjective observation was made by several observers concerning the triangles and squares, i.e. in both cases, prior to positive recognition, they had been often aware of certain recognition cues, in that both

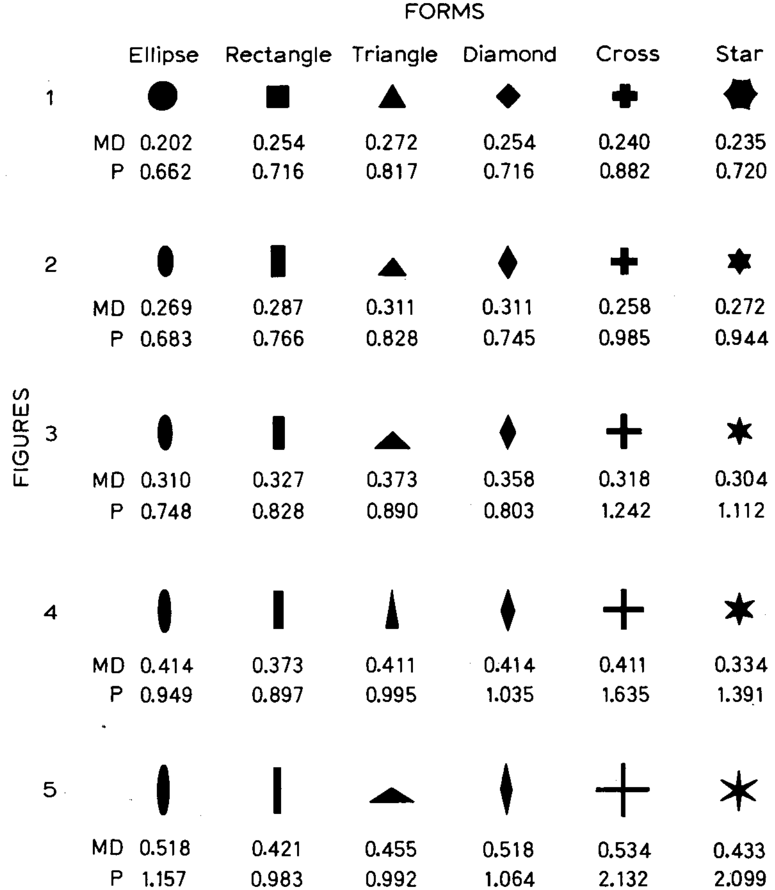

Fig. 5.1. The experimental forms and figures studied by Casperson. Maximum dimensions (MD) and perimeter (P) are given in centimetres for the smallest figures used. Larger figures with the linear dimensions scaled by factors of 1.5, 2.0, 2.5, 3.0, 4.0 and 5.0 were also studied. (Reprinted from Casperson[12] by permission. Copyright (1950) by the American Psychological Association).

triangles and squares tended to scintillate, growing points which varied between 3 & 4 and not always in the correct locations. For instance it was a common experience to see the triangle upside down before resolving it the correct way up. Such subjective comment is important to an understanding and modelling of the visual process and is presumed to be due to the combination of effects due to the retinal mosaic and the involuntary eye movements. Other very useful subjective comments on appearance of objects at recognition threshold are to be found in Salaman's studies[8].

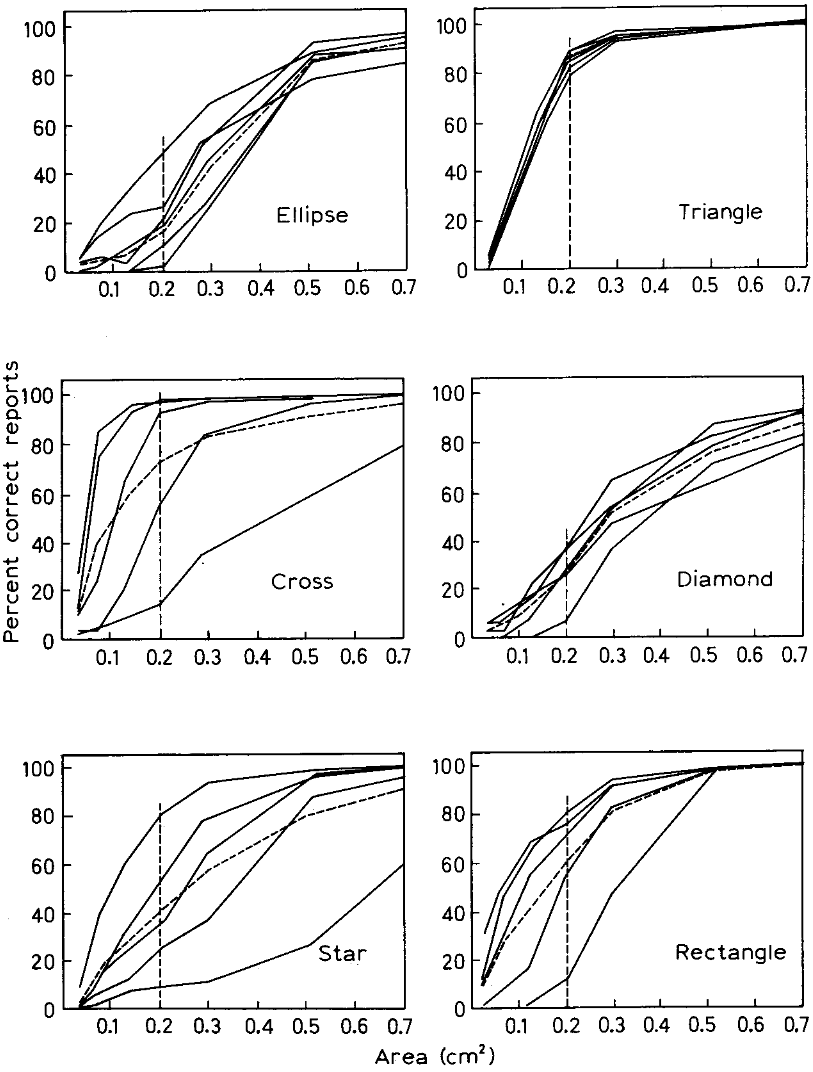

Fig. 5.2. The relationship between area and percent correct reports found by Casperson (each point represents 480 judgements). Solid lines represent the functions for the various figures within a particular form. The dashed lines represent the mean curve for each form. (Reprinted from Casperson[12] by permission. Copyright (1950) by the American Psychological Association).

Results of several studies show recognition threshold varying directly with 'compactness'* (e.g. Bitterman, Krauskopf & Hochberg[9] and Engstrand and Moeller[10]). Others find that, whilst form does affect recognition threshold, neither perimeter, area nor *P/A* are good predictors (e.g. Fox[11]). Casperson[12], in an attempt to resolve some of the conflict, set up an experiment utilising 30 shapes, five each of various forms of rectangles, ellipses, triangles, diamonds, crosses and stars. His stimuli, all presented at high negative contrast, are reproduced in Fig. 5.1. It will be seen that these stimuli include a disc, a square and an equilateral triangle as three of the most compact forms. He presented these stimuli in random order at various sizes to 20 observers, each figure being seen by each observer at each presented size 24 times. He then computed the percentage correct responses for each stimulus as functions of area, perimeter and maximum dimension. He found no common behaviour for the different forms. For instance, whilst the area was a good predictor of threshold for all triangles it was a very poor predictor of threshold for stars and crosses as shown in Fig. 5.2. On the other hand, the maximum dimension or perimeter were found to be good predictors for stars but very poor predictors for ellipses and diamonds. There thus seems to be no one simple measure of form which can be used as a universal predictor. Casperson realised that his results may possibly be observer dependent, so he carried out an analysis of variance on the results. This showed that, whilst there was a significant observer difference, this was completely swamped by the difference between forms.

In an attempt to approximate real life more nearly, whilst still using essentially geometrical forms, BAC(GW) carried out a recognition experiment using 4 stylised shapes[13]. These shapes, shown in Fig. 5.3, were all formed from

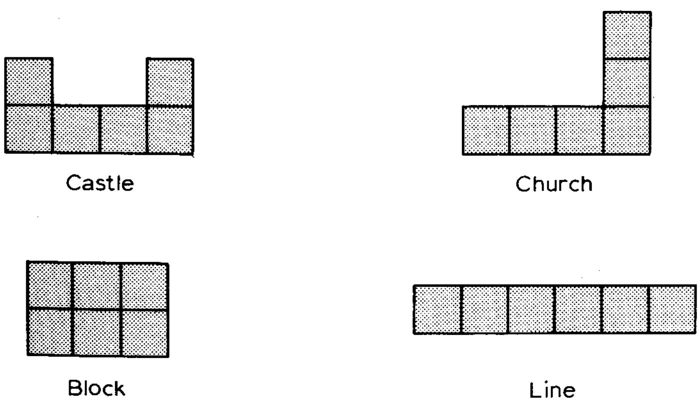

Fig. 5.3. The 4 stylised shapes used in the B.A.C. (GW) recognition experiment.

*Compactness is a term used by Zusne[2] and others to describe forms of low aspect ratio and simple contour – characterised by a low perimeter to area ratio (*P/A* ratio).

6 unit blocks, and were presented at high negative contrast in random order after observers had been thoroughly briefed. It was found that the recognition thresholds for these forms were such that the unit blocks subtended around 0.3 mrad at the observer's eye. If the subtense of the unit blocks is compared with the detection threshold for a square or circular target of similar contrast it is found to compare closely. Hence such a finding has been taken by some as a tentative confirmation that recognition may be equated to detection of detail for approximate predictive purposes.

5.2 SNELLEN LETTER TESTS

A recognition task familiar to most people because of its widespread use by opticians as an eye test is the Snellen letter test. This, in its normal usage, consists of the reading of a series of high contrast black letters on a white background in rows of decreasing size until an error is made. Hence it is really a legibility test. The letters used obey standard laws of construction[14] (see Fig. 5.4) and it is from them that a person's eyesight is defined in terms of a ratio such as those commonly quoted (6/x or 20/x). In these ratios the numerator refers to the viewing distance in metres (6) or feet (20) respectively and the denominator refers to the distance at which the *detail* of the letters subtends 0.292 mrad. Normal vision is usually taken as 6/6 or 20/20, although some eyes have acuity as high as 6/3. This form of eyesight testing is useful in modern western civilisation, since it effectively defines a person's ability to read standard print. However, as a measure of recognition threshold it leaves something to be desired since it has been shown by several workers (e.g. Lythgoe[15], Ludvigh[16] and Mandlebaum and Sloan[17]) that contrast and luminance both affect ability to interpret letter shapes.

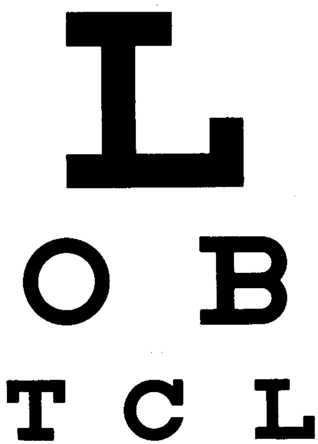

Fig. 5.4. Illustrating the construction of Snellen test letters and charts. The lines and serifs have a thickness one fifth of the height or width of a whole letter.

In an endeavour to make Snellen letter testing more universally applicable to recognition tasks, some workers have attempted experimentation using Snellen forms of letters of various contrasts and at various background luminance levels. Some have also attempted to identify this form of testing more closely with other threshold experimentation by presenting random letters from a limited set in a statistical fashion and by recording mean recognition threshold as that for 50% correct recognition rather than approaching 100% as used by opticians. Typical of work on these lines is that carried out in our own laboratory by Spicer[18,19], who studied the effect of both contrast, field luminance and binocular/monocular viewing on mean recognition thresholds for limited sets of Snellen letters, together with observer interactions. In these experiments Spicer used typical opticians' Snellen displays reproduced at various contrasts. On each line representing visual acuities of 6/9 and better one letter was cut out and a system arranged so that any one of a limited set of letters of the same size could be presented at random. Luminances of 41 and 6 900 cd/m^2 were used in combination with contrasts of -0.09 and -0.85. In order to reduce variance, and to limit the set of letters to be presented in these experiments, the results of a study by Coates[20] were invoked. This study implied that some 11 letters of the alphabet were a sufficient set to use for this form of experimentation.

The findings from Spicer's experiments were as follows:

(1) That the contrast of the letter has a major effect on recognition threshold.
(2) That there is an interaction of contrast and scene luminance – at high contrast the lower the scene luminance the lower the recognition threshold whilst at low contrast the lower the scene luminance the higher the recognition threshold.
(3) That the recognition threshold for binocular viewing is only marginally lower than for monocular viewing (of the order of 5 to 10% in linear size). This is in marked contrast to the difference in detection threshold for simple shapes between binocular and monocular viewing which in general is a factor of 40% (i.e. $\sqrt{2}$) in contrast or 20% in size (see Section 2.10).
(4) That there are significant observer differences in relative performance as a function of contrast and luminance.

Having found the foregoing significant effect of contrast and luminance, Spicer proceeded to investigate, for a group of 8 of the observers used in the Snellen tests, the correlation of the various visual acuity scores with performance in various detection tasks[21]. The detection tasks chosen were the detection, from photographs, of high and low contrast aircraft seen against structured (cloud) and unstructured backgrounds, and of 4 miscellaneous ground features (bridges and isolated buildings) as seen from the air. These together were considered to be typical of the more simple forms of realistic detection exercise. Non-parametric rank statistics were used to compare various measures. The only significant correlations obtained for the ground features were for one of two isolated buildings, whilst the only aircraft situation providing high correlation was that of a high contrast aircraft against a structured background, this latter providing high correlation with *all* the visual acuity scores. Some of the other comparisons showed very low correlations and serve to imply that Snellen testing is not a good measure of relative visual performance for many real-life detection tasks (although it is of course possible that it may yet be found to be a good measure for real-life recognition performance).

5.3 OTHER LEGIBILITY TESTS

Several other forms of what may be described as legibility tests have been used over the years (e.g. Le Grand[1]). By far the most common of these – and one which has become a standard experimental stimulus for many purposes – is the Landolt 'C'. This stimulus, shown in Fig. 5.5, is really an annulus with a thickness to outside diameter ratio of 1:5 from which a slice, of width equal to the annulus, has been removed. As such it provides a very versatile stimulus for a form of recognition task, since below recognition threshold it is indistinguishable from an annulus. Thus gap orientation can be used as the recognition task,* simplifying what can otherwise be a problem of preparation and presentation of varied stimuli. Alternatively the Landolt 'C' may be included with several annuli, providing a well defined search task.

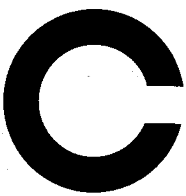

Fig. 5.5. Illustrating the construction of the Landolt C. The line and gap widths are each one fifth of the outer diameter.

As with Snellen letter testing, the majority of work with Landolt C's has been carried out at high negative contrast. Results of such experiments are normally considered to yield a performance in terms of visual acuity, defined as the reciprocal of gap width for recognition in this case. A typical trend of this form of visual acuity with luminance is shown in Fig. 5.6 (from Pirenne and Denton[22]).

Other forms of legibility test are various forms of bar pattern. Of these, some of the more common are the Foucalt chart, the 2-bar Cobb element and the American 3-bar pattern (see Fig. 5.7). When such patterns are used for threshold studies rather than the Landolt C, slightly different trends of performance with variation of luminance are found (e.g. Le Grand[1]). Such patterns are also

*Often called detection, but the term recognition is preferred by the author since the annulus defines a specific local search task.

sensitive to orientation, yielding 7–20% inferior performance if oblique than if horizontal or vertical, and are highly susceptible to astigmatism (e.g. Leibowitz[23]).

Limited studies have been carried out using bar patterns of low contrast for short presentation times and with inverse contrast. As reported for simple

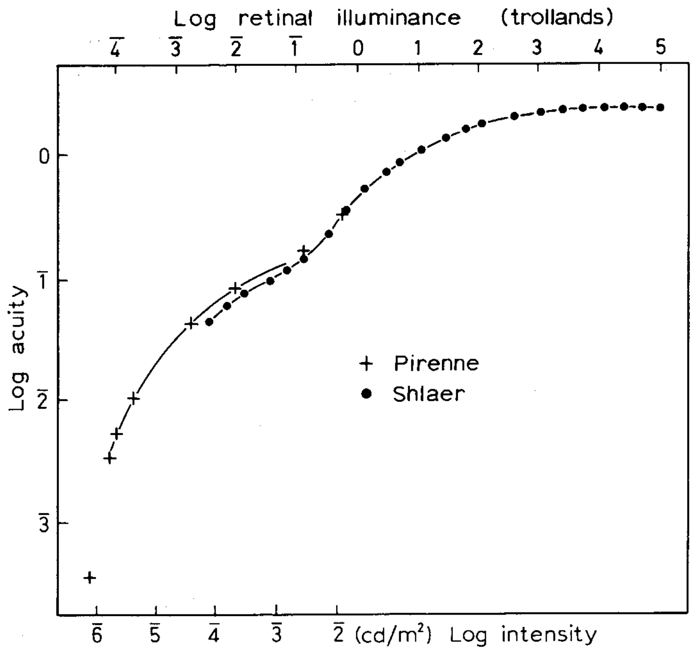

Fig. 5.6. Variation of visual acuity measured with Landolt C's as a function of light intensity. (Reproduced from Pirenne and Denton[22] by courtesy of Nature*).*

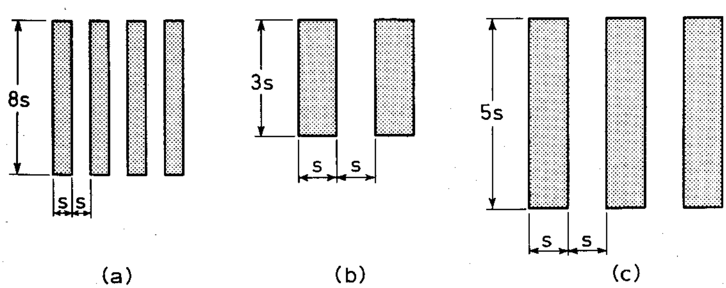

Fig. 5.7. Illustrating the construction of elements of various test patterns. (a) Foucalt, (b) Cobb, (c) American 3-bar.

detection thresholds in Chapter 4, it appears from these studies that gap detection is also considerably dependent on contrast, presentation time and, under certain conditions, sign of contrast[24,25].

5.4 COMPLEX SHAPES

So far our considerations of recognition have been largely confined to choice between a variety of simple geometrical shapes or standard letters. In normal visual activities other than reading, the form of recognition which must be employed may be vastly different to these very specific situations. It thus becomes necessary to consider what controls the recognition of complex shapes. Such complex shapes may be one of a very few or one of a very many, and may have luminance structure within them or may have a luminance interaction with their immediate surround. In order to be able to make predictions about visual recognition performance in such situations it is necessary to study what it is about a stimulus that permits its recognition in a given situation. Although a considerable amount has been written about this problem in recent years (see Zusne[2]) the full understanding still remains somewhat obscure. It is the author's opinion, in common with that of Zusne, that a very considerable amount of work is yet necessary before we shall be in a position to predict performance in other than the simplest cases. In the meantime a number of items of work which have been reported are recommended for the reader's attention.

Attneave[26-28] chose to approach the problem by assuming that possibly it was the local parts of the profile of an object which allowed its recognition. Following this line he produced a series of outline shapes with irregular contours and, allowing each of several observers 10 dots with which to do their best at defining each figure, produced a statistical impression of the 'importance' of various local parts of the profile. Fig. 5.8 shows a typical data set. As can be seen, there appears to be a strong concentration of 'importance' in the regions of maximum rate of change of contour direction, with virtually no importance given to straight regions of the contour. This finding leads on to a range of optical illusions which tend to support the hypothesis. The range of illusions referred to (e.g. Zusne[2], Postman and Brunner[29] and Gregory[30]) are characterised by incomplete figures which are universally 'filled in' by the brain from limited data presented. An example is shown in Fig. 5.9, where only a minimal amount of data at the corners of a possible triangle is sufficient for immediate visualisation of the whole triangle.

Attneave's work has been hailed as a milestone in work on perception of form. Not only did it point strongly to the conclusion that the main information associated with a two dimensional shape is contained in the contour, and primarily at points of greatest change of direction of contour, but also it enabled methods to be proposed for generation of random 2-dimensional shapes of better equivalence than used previously[28].

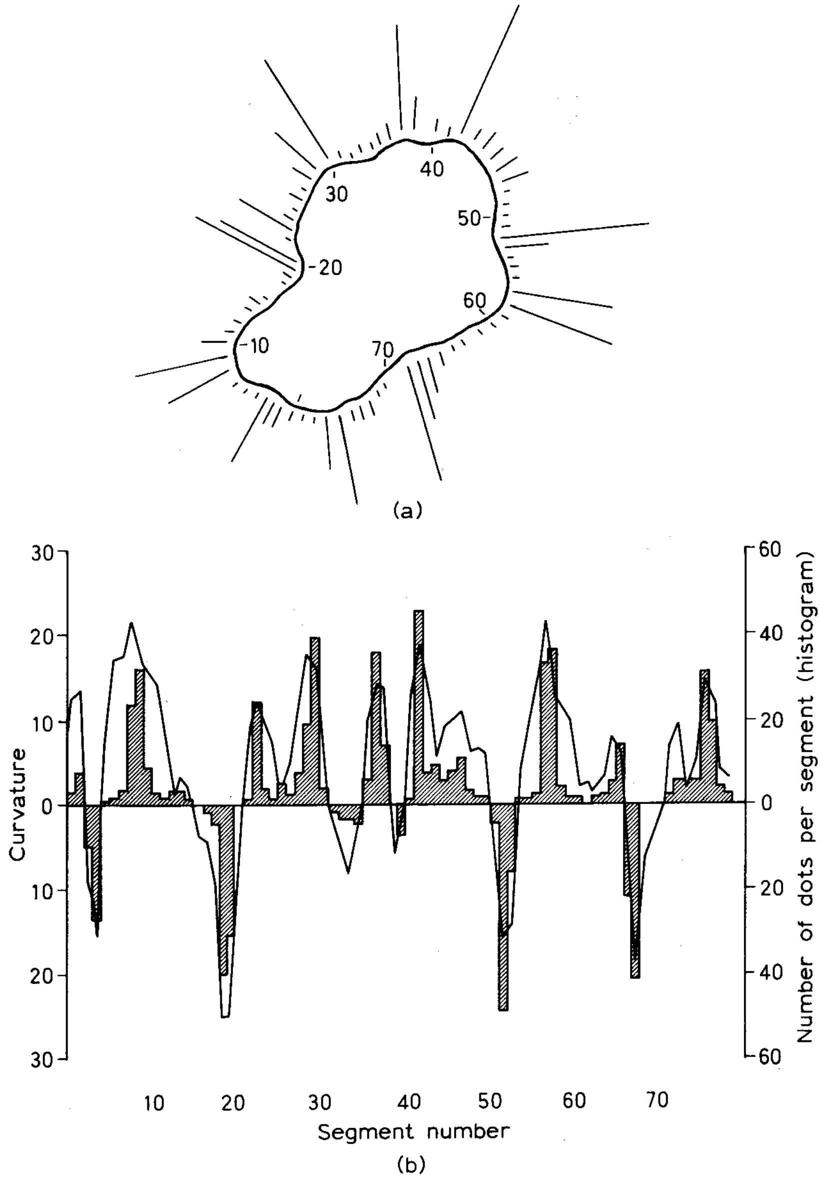

Fig. 5.8. Subjective importance of parts of a contour. (a) Typical contour studied – radial bar lengths are proportional to number of selections of that part of the contour as being important. (b) The number of selections of local importance compared with the local curvature of the contour, showing high correlation. (Reproduced from Attneave F. (1951) Research Note P & MS: 51–8 by courtesy of the Human Resources Center, San Antonio).

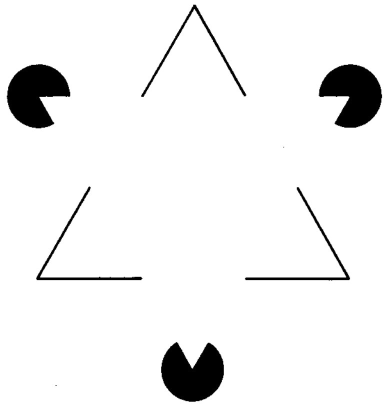

Fig. 5.9. A typical illusionary figure. There is a strong subjective impression of a solid triangular figure although no such figure exists.

An important point concerning the recognition of complex shapes is that found by Goodnow[31]. He experimented with aeroplane silhouettes and schemetised faces, in each case varying 3 characteristics. He found that, in such a task, observers only ever used one or two of the three variables to effect identification. Zusne[2] claims that other experimenters also find evidence of selective attention to particular physical cues in the case of complex objects.

5.5 THE RETINAL IMAGE AT RECOGNITION

A powerful approach to the basic processes of recognition is provided by modern computational techniques, whereby the retinal images of objects may be generated either mathematically through a digital computer or optically by means of spatial filtering. One or both of these techniques are in fairly common use in a number of laboratories. In the first, a two dimensional convolution is

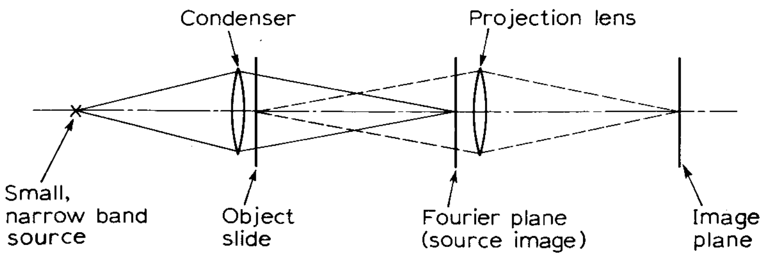

Fig. 5.10. The basic optics necessary for Fourier plane filtering.

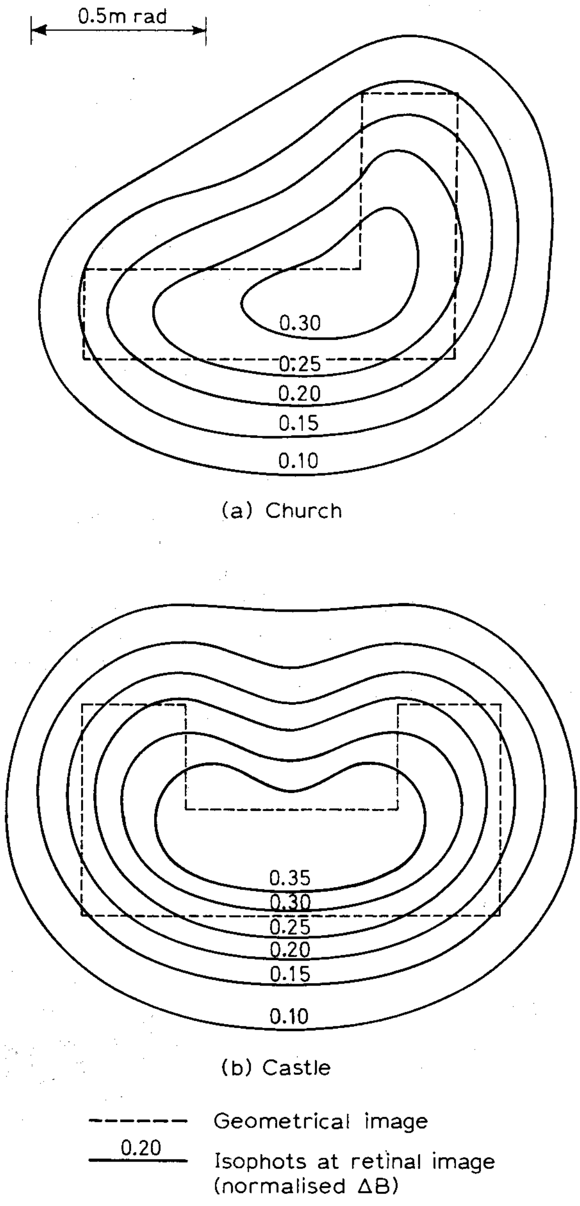

Fig. 5.11. Retinal image isophots for two of the stylised shapes shown in Figure 5.3 when viewed at an angular subtense resulting in a 50% probability of recognition (free choice) from the set of four.

carried out of the object to be viewed with the optical point spread function of the average human eye at the appropriate scaling, due allowance being made for involuntary eye movements. The computer can then be programmed to produce a two dimensional isophot diagram of the retinal image (e.g. Lavin and Overington[32]). In the second method relatively monochromatic light is used to generate a Fourier plane in which all object structures are effectively presented as frequencies[33]. If a graded transmission filter is then placed in this Fourier plane, such that it attenuates the higher frequencies, a softening of the picture will result. Since the frequency response function is the Fourier transform of the line spread function (see Chapter 10), such frequency filtering of a controlled nature in two dimensions is akin to convolution of the object with a point spread function. The optical system is completed by fitting a lens which reconstructs an image of the object as if it had been viewed through an optical system having a point spread function whose Fourier transform was of the form built into the frequency transmission filter. The basic optics necessary for such an operation are shown in Fig. 5.10. The resultant image from such a system may be either viewed through an eyepiece for direct visualisation or recorded on film for subsequent inspection. Much enlarged representations of the retinal image thus presented have been used for 'recognition' experiments so that attempts may be made to correlate the physical data available at the retinal image with recognition performance[34,35]. For such studies there appears to be an optimal enlargement, this being sufficient to mean that a second passage of image information through the optics of the eye produces negligible further degradation, whilst still permitting the entire image to be observed by near-foveal vision.

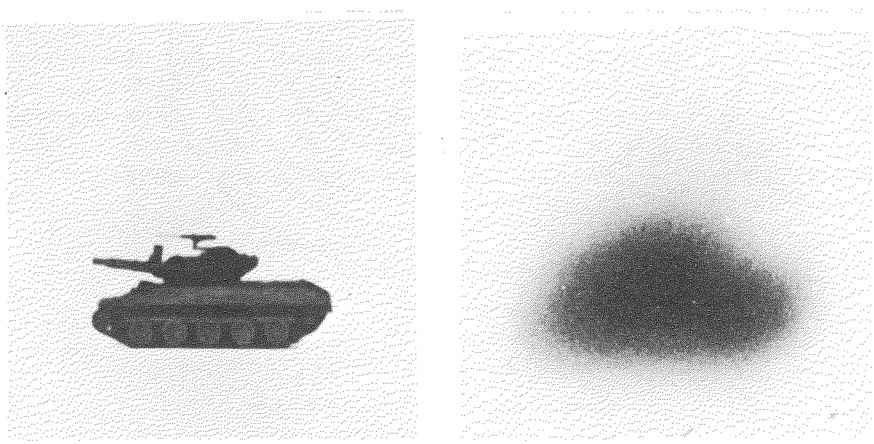

Fig. 5.12. A side view of a tank and an optically-generated representation of the retinal image when viewed to subtend an angle permitting 50% probability of recognition from a set of 30 military vehicles and confusible objects by trained personnel.

The resulting pseudo-retinal images of objects at recognition range by either computer convolution or optical degradation are striking for their lack of sharpness and detail. Figure 5.11 shows isophot plots of the retinal images of the stylised stimuli labelled *castle* and *church*, as shown in Fig. 5.3 and described in Section 5.1, when at 50% probability of correct recognition from a set of six similar shapes. They will be seen to have retained only minimal shape. Figure 5.12, on the other hand, shows the side view of a tank and the typical 'retinal image' of the tank at 50% recognition threshold for military observers, as produced by optical spatial filtering[33]. Again it will be seen to have retained only minimal shape and structure. The implications of the foregoing on attempted modelling of the visual processes will be discussed in Chapter 12.

5.6 EFFECTS OF ORIENTATION AND LEARNING

Experience, expectancy and familiarity are very important factors in recognition. Forms normally seen only in one position (e.g. an outline of a country on a map) are difficult to recognise when rotated, even though one may be very familiar with them. Such mono-orientated objects are hardest to recognise when inverted. Everyday objects which we are accustomed to seeing in several positions (e.g. pencils, keys, books) are much less sensitive to orientation[36].

'Normal' orientation may be defined in either of two ways – in the environment or on the retina. This raises a question of how recognition is affected when the form is tilted but the head remains upright, when the head is tilted and the form remains upright or when both are tilted together. The consequences of the two definitions of orientation were first studied by Oetjen[37], who found recognition performance was only good when the orientation of a form on the retina was maintained. Thouless[38] obtained results using ambiguous figures which tended to confirm these findings. On the other hand Rock[39] obtained results which suggested that the direction in the environment is most important and that retinal orientation is of little importance. Yet again, Braine[40] found that establishing a frame of reference on the retina by stating exactly how forms would appear did not help when used in addition to simple instructions that disorientated forms would appear.

If a form was learnt in one part of a visual field, Dees & Grindley[41] found that this was an assistance when the form was presented in a different part of the visual field. Conversely Lordahl *et al*[42] appeared to find that such learning had an adverse effect.

5.7 FORM FIELDS

So far in this chapter, where thresholds have been considered, it has been mostly assumed that foveal fixation was employed for interrogation. Obviously there are occasions when it is desirable to know the extent of the visual field within which particular recognition can be accomplished and, as with detection, performance *must* be expected to fall off with increasing angle of eccentricity. According to Anstis[43], the reciprocal of visual acuity for Snellen letters increases linearly with distance from the fovea out to an angle of eccentricity of about 0.5 rad. Similar findings for other acuity measures are reported by Le Grand[1]. Day[40] proposed a theory for foveal acquisition which postulated that at area 17 of the striate cortex, usually considered to be the first stage of central processing[45], there will be an activity about the boundary of figure and background which must reach one level for detection, a higher level (some 15 times that for detection) for indefinite form perception and a higher level still for definite form perception. He then applied this concept to peripheral form perception[46] and made various predictions as to what would be seen as various objects were brought progressively towards the fovea from the extreme periphery (e.g. white spaces enclosed in a figure would be seen first as filled in, L and T shapes would be seen first as roughly triangular, cross shapes would be seen first as a hazy blur and then like a diamond). All these predictions were then confirmed in an unpublished experiment. Graefe[47] agrees in general with Day's theory but considers it is incomplete. He suggests for instance, that, whilst some corners may be seen blurred, others may be seen sharpened. Equally, unjoined lines may be seen joined up and *vice-versa.*

The extent of form fields is, in general, dependent on a variety of factors including stimulus size, stimulus contrast, field luminance, contrast/area interaction, etc.. The only consistent finding regarding the size of form fields is that, for geometric shapes, the triangle is consistently seen best at the greatest eccentricities. Equally there seems good agreement that, within geometric shapes, the hexagon and octagon have the smallest form fields[48]. Of particular practical importance is the recent work of Bouma[49], who has studied the legibility of strings of letters presented in the parafovea. He has studied both random letters and words and has found that, in this complex recognition task, scores for end letters farthest from the fixation point are superior to scores for end letters closest to the fixation point. Thus in a complex field there appears to be a strong interaction between local visual acuity and data complexity.

5.8 PROFILE RECOGNITION

Another aspect of recognition which may form part of the total human visual capability is the ability to recognise the form of the profile – that is, whether it is sharp or of a given blur form. Campbell[50] has provided a useful insight into this in the extensions of his Contrast Sensitivity detection threshold work reported in Chapter 4. He has studied the threshold levels for recognition that a one dimensional bar pattern has other than a sinusoidal spatial luminance modulation. Work carried out using square, rectangular and sawtooth modulations has produced strong evidence that the threshold for recognition of profile form of periodic patterns by an experienced observer is governed by the threshold of the harmonic whose presence is necessary to define the waveform. For instance, for recognition of square from square or sinusoidal it is necessary to reach the detection threshold for the *3rd* harmonic. Conversely, for recognition of a sawtooth from sawtooth or sinusoidal it is necessary to reach the detection threshold for the *2nd* harmonic. Campbell has interpreted these findings as evidence of the existence, in the neural system, of effectively tuned circuits responding to each of several narrow bands of spatial frequency. Other studies related to this idea of neural tuned circuits are discussed in Chapter 12.

5.9 DYNAMIC EFFECTS

If one is attempting to recognise moving objects, then it may be that the object in question is large and appears unexpectedly for a short time, or it may be that the object is moving rapidly but in a relatively known fashion. In the former of these cases the recognition decision must be made on interpretation of a smeared retinal image. Such is, for instance, the situation when a threshold experiment is carried out with moving Landolt C's. Since the recognition (or gap detection) in this case consists of the recognition of a smeared gap it should be fairly clear to the reader that ambiguities can creep in due to the orientation of the gap. For horizontal motion, if the gap is at North or South one would get a different answer than if the gap is at East or West. In addition it is found[51] that there is an ambiguity between gap at East and West positions. This latter effect is believed to be due to after-imagery.

In the case of study of objects moving predictably, or in a known part of the visual field, because the basic stimulus for recognition is always well above detection threshold, it is usually possible for the eyes to 'lock on' to the moving stimulus, thus converting the task to one approximating to a static recognition task. This form of viewing – known as ocular pursuit – will result in performance degraded from the static to a lesser or greater degree according to the predictability of the stimulus motion and its rate of angular motion. Some statistical studies of eye motions in attempting ocular pursuit tasks have recently been published by Cheng & Outerbridge[52]. For relatively low frequency sinusoidal motions it has been shown possible to achieve perfect ocular pursuit with training. Under such conditions the performance would be expected to be the same as for static viewing. As the frequency or amplitude of sinusoidal motion is increased, there comes a time when the eyes fail to follow adequately. Under such conditions the performance may be expected to approximate to the normal dynamic visual acuity for the residual motion. Finally, at very high angular rates the eye fails to track at all and the performance falls to that associated with the unpredictable motion situation.

The most systematic studies of degradation of foveal visual acuity during ocular pursuit appear to have been carried out by Ludvigh and Miller. In his early work Ludvigh found, using Snellen letters as test objects, that when motion is in a horizontal plane, visual acuity falls markedly as the angular velocity is increased from 0 to 2.2 rad/s[53]. Subsequently[54] he extended his studies to include velocities up to 3.5 rad/s. During his studies he noted that high intensities of illumination particularly improve visual acuity when the test object is moving. In later work[55-57] Ludvigh and Miller found that their experimental results could be fitted by an equation of the form

$$1/u = 1/u_s + \omega^3/u_d \tag{5.1}$$

where u is the visual acuity and ω is the angular velocity.

The quantity u_s in Equation 5.1 is thus an estimated value of the static acuity whilst u_d is an effective measure of dynamic acuity, being large when acuity does not deteriorate rapidly as anglular velocity is increased. The value of u_d is found to be very dependent on particular test conditions and observers but a very high correlation for given conditions and observers was found by Miller and Ludvigh[58] between the u_d values obtained for horizontal and vertical motions. Typical forms of the degradation of performance with increasing angular velocity are shown in Fig. 5.13. In this figure are shown the cumulative data of Ludvigh and Miller and the cumulative data of Rose[59] fitted by functions of the form of Equation 5.1. The reason for the striking difference in rate of deterioration is that Ludvigh and Miller's data represent fall-off of performance

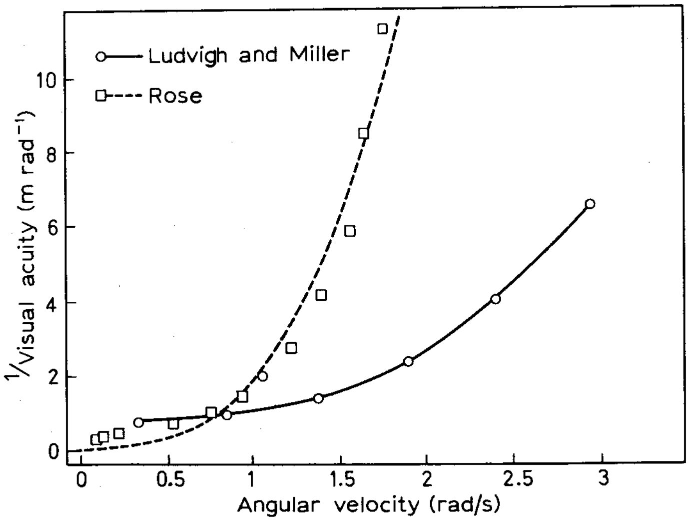

Fig. 5.13. Typical forms of degradation of visual acuity with increasing velocity. (Reprinted from Miller and Ludvigh[57] by permission. Copyright (1962) by the Williams & Wilkins Co., Baltimore).

with constant exposure time whilst Rose's data represent fall-off with a constant angular presentation, the exposure time thus being reciprocally related to the velocity. A useful survey of the above and other work on dynamic visual acuity is to be found in Lavin[60].

Recent work by Lavin[51] has suggested that the cubic fit to data obtained with a constant angular presentation is only adequate over a limited range of velocities, it being contended that at high velocities there is a need to consider a limiting velocity above which there is no chance of seeing anything. As an approximation Lavin has found it possible to obtain a very good fit to his own collected data for a group of observers on a log/linear plot, despite very considerable observer differences, by an equation of the form

$$1/u = y_0 \exp(1.44v) + y_1 \exp(18.3v) \tag{5.2}$$

where u is the visual acuity, v is the limiting velocity in rad/s and y_0 and y_1 are constants peculiar to individual observers.

This collected fit is shown in Fig. 5.14. In this figure the data have been grouped by taking the data for one observer and then overlaying data for all

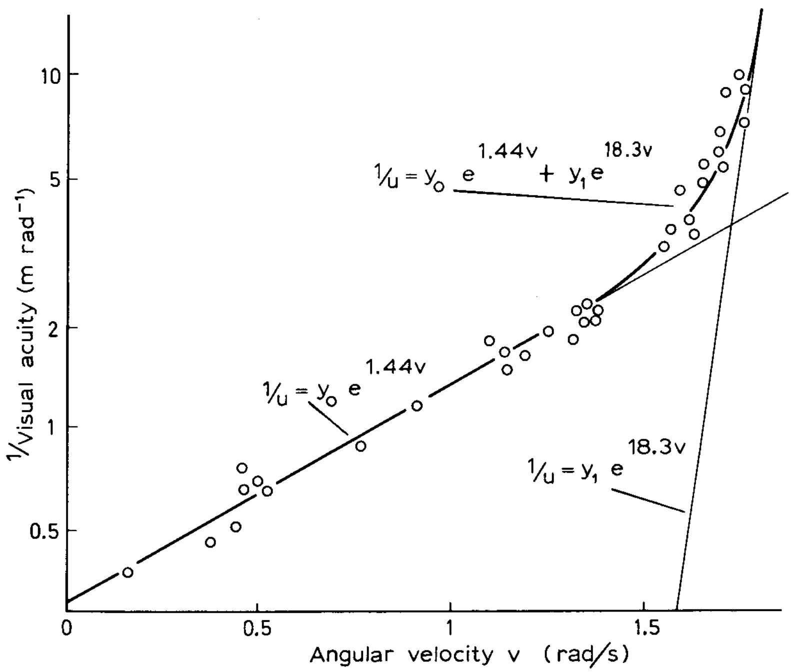

Fig. 5.14. The collected results of the foveal dynamic threshold study of Lavin (from Lavin[51]).

other observers by means of simple orthogonal shifting of the size and velocity axes.

5.10 DISCUSSION

In this chapter many facets of the problem of recognition have been referred to. However, it will be clear to the reader that the present situation is not a very tidy one. As Zusne says 'It would appear that in thirty years of studying form identification we have learnt little that can be stated with any certainty'. Nevertheless, it is hoped that the information cited will at least lead the reader to a fuller appreciation of the problems of this facet of acquisition.

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