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# Saccadic eye movements and visual cognition

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Abstract

Summary

This article concentrates on the human saccadic eye movement and examines its interest for psychologists both as an individual behavioural response and as a component of more complex perceptual behaviour. Research is reviewed which examines single saccades to targets in the visual periphery. This suggests a parallel processing model in which separate processes determine firstly the latency of the saccade and secondly its spatial components. The global effect is described whereby the amplitude of a saccade to an extended peripheral target depends upon the global properties of the target. Experiments show how this may be used to study the interaction of sensory and volitional factors in the production of saccades. Progressing to more complex material, various extra considerations are described relating to saccades produced when scanning sequences of symbols and text. This leads finally to a discussion of saccades when viewing pictorial material.

Key words : saccadic eye movements, peripheral vision, visual scanning.

Résumé

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Cette revue concerne la saccade oculaire chez l'Homme et l'intérêt que présente son étude en Psychologie, en tant que réponse comportementale individuelle et aussi en tant que composante de comportements perceptifs plus complexes. On y rassemble les données des recherches analysant l'organisation d'une saccade sollicitée par une ou plusieurs cibles présentées dans le champ visuel périphérique. Ces données suggèrent un modèle de traitement parallèle des stimulations visuelles où des processus distincts détermineraient d'une part la latence de la saccade et d'autre part ses composantes spatiales. On décrit « l'effet global » lié au fait que l'amplitude d'une saccade dirigée vers une cible incluse dans un ensemble d'éléments dépend des propriétés globales de l'ensemble. Des expériences montrent comment l'étude de ce phénomène peut permettre d'analyser les interactions entre facteurs sensoriels et cognitifs dans la préparation d'une saccade. On considère ensuite des situations plus complexes, et on s'intéresse aux divers facteurs qui interviennent dans la production des saccades au cours de l'exploration de symboles, de la lecture de textes, et enfin de l'examen visuel de matériel pictural.

Mots clés : saccade oculaire, vision périphérique, balayage visuel.

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# SACCADIC EYE MOVEMENTS AND VISUAL COGNITION[2]

by John M. Findlay

*RÉSUMÉ : Mouvements oculaires et connaissance visuelle.*

*Cette revue concerne la saccade oculaire chez l'Homme et l'intérêt que présente son étude en Psychologie, en tant que réponse comportementale individuelle et aussi en tant que composante de comportements perceptifs plus complexes. On y rassemble les données des recherches analysant l'organisation d'une saccade sollicitée par une ou plusieurs cibles présentées dans le champ visuel périphérique. Ces données suggèrent un modèle de traitement parallèle des stimulations visuelles où des processus distincts détermineraient d'une part la latence de la saccade et d'autre part ses composantes spatiales. On décrit « l'effet global » lié au fait que l'amplitude d'une saccade dirigée vers une cible incluse dans un ensemble d'éléments dépend des propriétés globales de l'ensemble. Des expériences montrent comment l'étude de ce phénomène peut permettre d'analyser les interactions entre facteurs sensoriels et cognitifs dans la préparation d'une saccade. On considère ensuite des situations plus complexes, et on s'intéresse aux divers facteurs qui interviennent dans la production des saccades au cours de l'exploration de symboles, de la lecture de textes, et enfin de l'examen visuel de matériel pictural.*

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## INTRODUCTION

Vision is the primary human sense modality. The quantity of information passed along the optic nerve is far greater than that in any other pathway of special sense, and a large proportion of the pos-

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terior part of the cerebral cortex is primarily concerned with the analysis of this message. With few exceptions, visual perception is a process which operates effortlessly, efficiently and continuously. It is pre-eminently an active process involving movements of the eyes and head to search and scan for visual information. Yet many of the most successful recent accounts of the process of vision (Marr, 1982; Regan, 1982) have been concerned with the processing of the static retinal image and largely ignore the mobility of the eyes. Some justification of this limitation comes from tachistoscopic studies which show that the visual information available in a single glance is extremely rich (Biederman, 1982). However, the thesis of this paper is that a study of eye movement activity in relation to vision is not only scientifically fascinating and challenging in ist own right, but also can provide new insights into the operation of the sensory processes involved in vision.

The article treats research on saccadic eye movements at three levels. The first few sections are devoted to considerations arising when isolated saccadic eye movements in very simple situations are considered. Our knowledge about this is sufficiently precise in many cases to seek realistic links with the physiology of the visual and oculomotor systems. The remainder is devoted to the situation where the eye makes a series of scanning saccades; this approaches more closely the normal use of eye movements. The second part of the paper is devoted to scanning sequences when the subjects look at discretely spaced symbolic material, with some reference to reading. In particular, attention is directed to deciding whether the principles developed in the first part remain valid. The final part turns to the question of pictorial material, where inevitably the complexities of the situation render any conclusions much more tentative.

## PSYCHOLOGICAL INTEREST IN SACCADIC EYE MOVEMENTS

The active nature of vision is evident in Figure 1 which shows a record of the gaze of a pilot whilst operating an aircraft simulator. The interpretation of this type of record is as follows. The linear sections of the trace superimposed on the scene represent saccadic movements of the eyes. They are rapid, jump-like, rotations of the eye which transfer the visual axis from one gaze location to the next. They are stereotyped movements, lasting some tens of milliseconds, and it is widely accepted that no useful information is extracted during the period of the movement. In addition to the blur and masking effects produced by the movement (Matin, 1975), a further process operates to suppress vision (Riggs, Merton and Morton, 1974). Vision only occurs whilst the eye is stationary, indicated in Figure 1 by the locations at which the trace shows a change of direction; these are the 'fixation pauses' and typically last between 200 and 500 milliseconds. It is the sequence of saccades and fixation pauses that we shall be concerned with here. The other types of eye movement (vestibulo-ocular and optokinetic reflexes, pursuit and vergence) are of considerable interest and importance, but operate to a large extent independently of the saccadic system (Rashbass, 1961; Barnes, 1979).

Three reasons may be advanced why saccadic movements should be of great interest to psychologists. Firstly, they form a ubiquitous aspect of behavioural activity. During the waking hours, the eyes rarely remain stationary and sleep too is characterised by periods of brisk saccadic activity. As a very rough estimate, every individual may make one million saccades each week. The second reason concerns the simplicity of the response. For almost all studies of concern to psychologists, each eyeball may be adequately considered to be a globe rotated by three pairs of muscles. Since the load presented to these muscles is unvarying, the movements involved and the corresponding patterns of innervation have a stereotyped and reproducible character. Furthermore, saccades are conjugate movements; both eyes rotate in essentially the same way when a saccade is produced. This is true both for movements involving different depth planes as well as for movements in a single depth plane, as when viewing a picture. The latter case is by far the most frequently studied and for this a record of the type shown in Figure 1, together with a knowledge of the time course of the movements, is a sufficient representation of the data. This conceptual simplicity regrettably has to be contrasted with the complexity of the technical problems which must be overcome in order to obtain a satisfactory method for recording and analysing the eye movements. The oculomotor laboratory frequently presents an awesome array of sophisticated optical and electronic equipment. However recording methods have improved greatly in reliability over the years, and computer assistance has alleviated the arduousness of the task of data processing.

The final reason why the oculomotor system should be of interest to psychologists concerns the very intimate link which exists between eye movements and the processes of visual cognition. It might be argued that the simplest situation in which a saccadic eye movement occurs is the so-called 'fixation reflex', in which the sudden appearance of a target in the visual periphery elicits an orienting movement. Even here the saccade produced is a manifestation of a solution to a non-trivial problem in information processing. A conversion must be made from a retinal position signal, coded spatially, to the appropriate temporal sequence of activation of the eye muscles to move the eye by the appropriate amount. As shown later, this simple sensorimotor link has been extensively studied at the level of detail. In more complex situations, a combination of sensory and central factors interact in the production of the saccade. The intrusion of central influences may be frustrating to the sensory psychologist whose orientation is towards isolating stimulus factors. But a more positive approach is to welcome this interaction as an opportunity to investigate the interface between sensory and cognitive processes. Success in such an endeavour clearly requires a satisfactory understanding of the basic principles of oculomotor functioning. These are now reasonably well established from the study of saccades occurring in simple laboratory situations.

Fig. 1. — Record of pilot scanning the controls in a Boeing 737 simulator (Spady, 1978)

The next few sections consider some of the findings to have emerged from studies at this level, commencing with a brief overview of relevant work on the physiology of oculomotor control.

## THE NEUROPHYSIOLOGY OF SACCADIC EYE MOVEMENTS

Investigation of the physiology of the saccadic eye movement system has proceeded vigorously and productively in recent years. The work is presented in several recent symposia (Bach-y-Rita, Collins and Hyde, 1971; Lennestrand and Bach-y-Rita, 1975; Baker and Berthoz, 1977; Fuchs and Becker, 1981), and only a few salient points can be made here. The dynamics of the eyeball and musculature are sluggish (the coefficient of viscous damping is high) and thus, as first demonstrated by Robinson (1964), it is necessary to provide a 'pulse-step' of neural excitation in order to produce the rapid step movement of a saccade. This form of activation is produced by an interplay of excitatory and inhibitory activity in brain stem neurons. The brief duration of the movements, considered in conjunction with the relative slowness of the early (retinal) stages of vision, ensures that saccadic movements are ballistic in the sense that they cannot, once initiated, be influenced by subsequently occurring visual information. It has been frequently asserted that saccades are ballistic in a stronger sense; that the whole trajectory of the saccade is predetermined at the outset so that saccades of a particular amplitude are completely stereotyped. In contrast to this, a position which has recently received considerable support suggests that the saccadic command signal is generated by a goal-seeking process in some internal representation of visual space (Zee, Optican, Cook, Robinson and Engel, 1976; Mays and Sparks, 1980). This process takes some time to execute; consequently, if new information arrives at the level of the process, its operation may be modified to give rise to a saccade whose trajectory changes in mid-flight from that planned at the outset. Saccades with this character are observed on occasion.

The way in which such a process could be implemented physiologically is unclear. Studies of the spatial aspects of saccade generation have concentrated largely on the superior colliculus, a visual centre of the brain known to be intimately involved in the saccadic generation process. The colliculus is a layered structure and the upper layers receive a direct projection from the retina. This projection, like the retina itself, forms a two-dimensional map of visual space. Electrical stimulation of the deeper layers of the superior colliculus produces saccadic eye movements and it is possible to plot out a 'motor map', showing that the direction and magnitude of the eye movement varies systematically with the position of the electrical stimulation. The visual map and the motor map are formed in different layers of the colliculus, and may be considered as two two-dimensional sheets stacked back to back. An exciting result was obtained in the early seventies when it was shown that there was a correspondence between the visual map and the motor map (Schiller and Koerner, 1971; Robinson, 1972). The saccade produced by stimulation at a point in the motor map was exactly appropriate to direct the gaze to the corresponding location in the adjacent visual map.

The implication that the superior colliculus is a centre for 'foveation' is a very seductive one. There are problems with this straightforward view however. Firstly, the receptive field sizes in the superior colliculus are often extremely large. This complicates the picture but might also provide a clue to the detailed working of the sensorimotor transformation carried out (McIlwain, 1976). Secondly, the idea that the motor activity is directly triggered by the sensory activity has proved to be too simple (Wurtz and Albano, 1980). It appears that some second facilitating input is required. This may relate to another important convergence between physiological and behavioural studies. In both cases, evidence points to parallel processing. One mechanism (the 'WHEN' mechanism) is responsible for the decision to initiate the saccade. A second mechanism (the 'WHERE' mechanism) is concerned with the amplitude that the saccade will have. The physiological evidence for this has been summarised by van Gisbergen (van Gisbergen and Robinson, 1977; van Gisbergen, 1982). The distinction is also supported by behavioural evidence as described below. The concept of parallel processing has considerable significance for the interpretation of saccadic eye movements in more complex situations.

## THE PARALLEL PROCESSING MODEL

The idea that one process is responsible for the decision to initiate a saccade and a second, independent, process is concerned with its spatial parameters, also finds support from behavioural studies. One of the clearest lines of evidence comes from a situation first studied by Saslow (1967), and later by Ross and Ross (1980). A subject is asked to follow a target spot with his eyes as rapidly as possible. When the target jumps to a new position in a step-like manner, the subject will produce a saccade. The saccadic movements in this situation are very regular and stereotyped and, for moderate sizes of target displacement, the amplitude is usually matched accurately to the target step size. The latency of the movement, that is the time between the appearance of the target at its new position and the commencement of the eye movement, is influenced by a number of factors. One of the most significant of these concerns the temporal relationship between the events involved. The stimulus in this situation may in fact be considered to be a composite event with two components; first, the disappearance of the target at the fixation position, and second, the appearance of the target at the new position. Under natural conditions of target movement, these events are synchronous. However it is possible to manipulate this relationship experimentally. On the one hand the fixation spot may disappear before the new target appears, leaving a bref temporal 'gap' in which no target is present. On the other hand the reverse situation is when the stimulus remains briefly present in its first position following the target appearance in the new position, leading to a period of 'overlap'. The saccade latency is found to depend strongly and systematically on this temporal variable; when there is a gap the latency is short and when there is overlap it is long. The difference is substantial, increasing from a value around 150 msec when there is a 50 msec gap to around 250 msec when there is a 50 msec overlap. Ross and Ross (1980) have shown that most of this effect relates to the temporal preparation involved since very similar results are obtained if the event at the fixation point is a stimulus onset or change rather than its disappearance. In summary, the results support the existence of a process (the 'WHEN' mechanism) which determines the instant at which a saccade will occur and has no concern with the spatial properties of the saccade.

A similar division of function has been postulated by Becker and Jürgens (1979), who propose a detailed model of the saccade generation process. This influential model is shown in Figure 2. The critical results on which it is based come from experiments in which subjects are asked to track a target spot which moves in a series of steps. On some trials, two steps follow in rapid succession with only a very brief pause (50-200 msec) at the intermediate position. Under these circumstances the second step can occur whilst the saccade to the first step is still in preparation thus revealing whether the new information provided by the second step is capable of influencing this preparatory process. It turns out that in this situation the critical variable is the interval between the second target step and the saccade, which Becker and Jürgens denote by the symbol D. This variable cannot be directly manipulated experimentally but the variability in the generative process is such that a suitable range of values may be observed if the interval between the steps is varied. Results show that characteristics of the first saccade are precisely dependent upon D, and insensitive to the other temporal parameters of the situation. For small values of D, the size of the first saccade is appropriate for the first step and identical to that of saccades elicited when no second step follows.

Fig. 2. — Main features of the model for saccade generation proposed by Becker and Jürgens (1979). The decision mechanism, responsible for the timing and direction of the saccade, feeds into a mechanism which computes the saccade amplitude by performing a temporal integration of a signal of target eccentricity, by sampling this input through a 'time window' of length. The final motor command is provided by the neural pulse generator (NPG). (Figure redrawn from Becker and Jürgens, 1979.)

For large values of D, the initial step is ignored and the first saccade is of a size and direction appropriate to the second step. Intermediate values of D lead to particularly interesting results. A plot of saccade amplitude as a function of D shows an amplitude transition function; at some point the amplitude of the saccade deviates from that appropriate to the first step, and there emerges a region in which the mean amplitude takes a progressive series of intermediate values as D increases. This indicates saccades are directed to intermediate positions between the target positions.

The commencement of this transition function shows the point at which the new information starts to have an effect and the value of D at this point gives the time for this process. Different values were observed by Becker and Jürgens (1979), depending on the configuration of target positions. Becker and Jürgens restricted consideration to saccades along the horizontal axis, and their results supported a separation of the processes determining the saccade direction, on the one hand, and saccade amplitude, on the other hand. If the second step was to a position on the same side of the fixation point as the first step, and also in the case (SP) in which the second step returned the target to the original position, then the minimum value of D at which the influence of the second step became apparent was 80 msec. If, however, the second step was on the opposite side of the fixation to the first step, then a considerably longer time (170 msec) elapsed before the saccades were modified. The interpretation given is in terms of the model shown in Figure 2. In this model, the decision about the saccade timing is taken by the same mechanism as that which determines the direction of the saccade. A second mechanism is concerned with the programming of saccade amplitude. Both mechanisms are activated by retinal information. The 'decision' mechanism requires merely an adequate trigger signal to initiate processing, whereas the 'amplitude computation' stage registers the spatial information. The decision mechanism 'fires' when the decision is made to produce the saccade. This initiates a passive 'look-up' process to compute the amplitude. In order to explain the transition phases in the amplitude functions, Becker and Jürgens postulate that this look-up process is not instantaneous, but rather takes a running average of the spatial information, providing a temporal 'window', in which the spatial information is averaged over a period of about 100 ms.

Although in general the evidence for parallel processing seems to be very strong, at the level of detail some doubts may be raised concerning the particular specification made by Becker and Jügens. The most substantive issue centres on whether, as these workers wish to suggest, saccade direction is programmed independently from saccade amplitude. One problem emerges from their own experimental results. Rapid modification of saccades by information which is ipsilateral to the target appears clearly only if the second target position is less eccentric than the first. If the second step moves in the same direction to produce a second position which is more eccentric, then the minimum value of D for modifiability is much greater than 80 ms. There is a similarity here between this finding and an earlier study on double step tracking carried out by Lévy-Schoen and Blanc-Garin (1974). These workers used a different method of analysis, but the principal finding was a difference in the ease with which a saccade could be modified depending on whether the second target position was more eccentric or less eccentric than the first. When the second position was nearer the fixation than the first position, the probability of a saccade being directed to the second position, rather than the first position, was increased. Moreover this applied irrespective of whether the second position was on the same side or on the opposite side as the first.

It must also be noted that the saccades studied by Becker and Jürgens were quite large (15 to 30 degrees) and outside the range in which most naturally occurring saccades are found. Bahill, Adler and Stark (1975) have measured human saccade amplitudes under naturalistic conditions and find that nearly all saccades have amplitudes less than 15 degrees. Frost and Pöppel (1976) have argued that saccades above about 15 degrees in amplitude are programmed in a different way from smaller saccades. Their suggestion rests primarily on the finding that eye movements larger than about 15 degrees always results in a double saccade. The first saccade takes the eye about 90 % of the required distance and a small corrective saccade accounts for the remainder. For smaller movements, a single saccade is more common although the double pattern may be observed. Another result which suggests a difference between saccades with amplitude less than 15 degrees and larger saccades emerges from studies of saccade latencies. The parallel processing model posits that the latency of a saccade is the outcome of a process (the 'WHEN' system) which merely requires an adequate trigger signal to initiate it. Thus when saccades are made to peripheral targets, the latency should not depend on the visual properties of the target. Results suggest that this prediction is fulfilled reasonably well for saccades to targets in the 1 degree to 15 degrees region (Findlay, 1983). However, almost all studies have found that latency increases systematically with targets eccentricity for eccentricities greater than about 15 degrees.

## PREDICTABILITY EFFECTS

Another piece of evidence for parallel processing of this nature comes from studies of the effect of advance information on a saccade. Saccadic latencies can be reduced if either the spatial or the temporal properties of the target movement can be predicted. The most substantial effects are found in the case of temporal predictability. Studies such as that of Cohen and Ross (1977), together with those already discussed (Saslow, 1967 ; Ross and Ross, 1980) have shown that when the time of occurrence of a new target is predictable, even though its position is unknown, the latency of the saccade may be reduced by as much as 100 msec. If, on the other hand, the spatial position of the new target is known, the benefit in the reduction of saccade latencies is much smaller, of the order of 10 msec (Posner, Nissen and Ogden, 1978); indeed in some cases no benefit has been observed (Heywood and Churcher, 1980). A currently favoured interpretation of the faster responses to targets occurring in predictable locations is in terms of a system of spatial attention which operates separately for overt eye movements to potentiate particular regions of visual space (Posner, 1980). An important result is that the effects of spatial predictability and of temporal predictability appear to be independent. This is shown in studies in which both spatial and temporal predictability have been manipulated. It is found that there is no interaction between the two variables; the effects of spatial predictability are the same whether temporal predictability is high and the saccades have short latencies, or temporal predictability is low and the overall latencies are much longer (Michard, Têtard and Lévy-Schoen, 1974; Findlay, 1981). Such an absence of statistical interaction is usually regarded as evidence for separate processing stages (Sternberg, 1969). The effects of spatial predictability are complex, as shown by results obtained by Gorea, Findlay and Lévy-Schoen (1980). Subjects were asked to saccade to targets which could occur in several possible positions; some of these were associated with high probability of occurrence and others with low probability. Figure 3 shows the resultant mean saccade latencies under various combinations of high and low probability locations. When 87.5 per cent of targets were on one side of the fixation point and 12.5 per cent on the opposite side, the saccades in the more probable direction were speeded by about 20 msec with respect to those on the opposite side. A second effect was observed when targets at one value of retinal eccentricity were made highly probable. This second effect appeared to be an additional, non-interacting one. If 87.5 per cent of the targets are at 3 degrees eccentricity and the remainder at 15 degrees, it was found that the latencies of saccades to the 3 degrees (high probability) positions was reduced, by a figure of about 10 msec, in comparison with those to the 15 degrees position. If the 15 degrees position was made the high probability position, with occasional targets at 3 degrees, the converse did not occur. In this case, the 15 degrees saccades were speeded, in relation to their latencies in the low probability condition. However there was no corresponding latency increase for the 3 degrees movements. Using the concept of spatial attention discussed above,

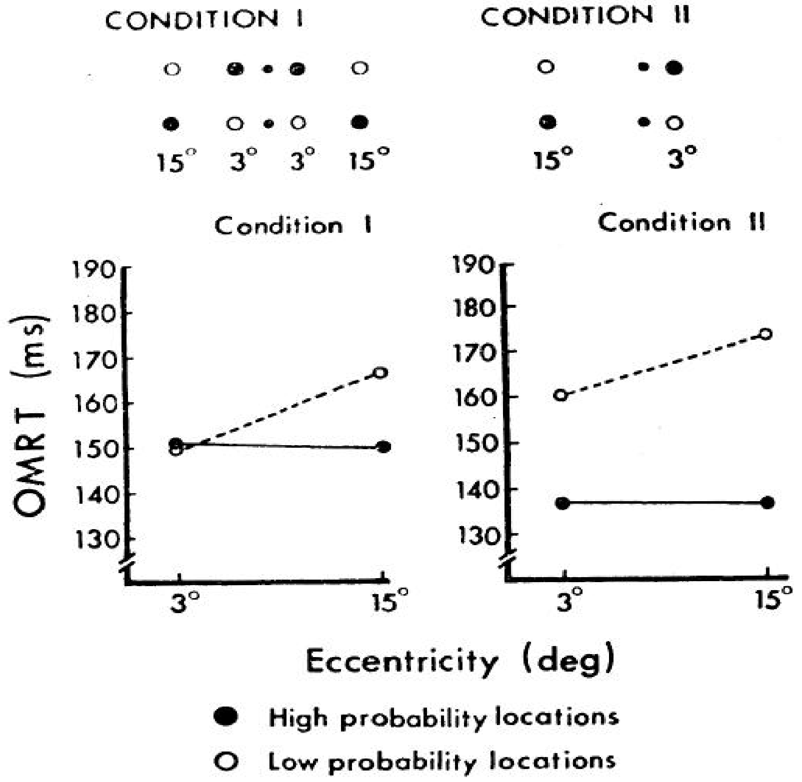

Fig. 3. — Data from the study of Gorea, Findlay and Lévy-Schoen (1980). Saccade latency is plotted against target eccentricity in various conditions where the probability of targets appearing in different locations was varied, according to the distributions shown. In condition I, targets appeared with equal probability on left or right but 87.5 per cent of the time at one eccentricity (either 3 degrees or 15 degrees) and 12.5 per cent of the time at the remaining eccentricity. There were thus four possible target locations. In condition II, there were only two possible target locations. Targets appeared with 87.5 per cent probability at one location and 12.5 per cent probability at the other. All combinations of left/right with eccentricities of 3 and 15 degrees were presented in counterbalanced blocks.

these results suggest that attention may be deployed to one side of the visual field, and may also be restricted to a particular region around the fixation point. However attention to one position in the field appears to include automatically attention to all proximal positions.

## SACCADE AMPLITUDES

The studies just described measure the latency of saccades and thus, on the interpretation given earlier, are concerned with the 'WHEN' system. A variety of results suggest that, at least in the case of saccades to newly appearing peripheral targets, the 'WHERE' system operates in an automatic, rather reflex-like, way. The peripheral stimulation largely overrides any prior expectancies and intentions that the observer may bring to bear. A simple result showing this comes from Posner *et al.* (1978) in the study already described. They found that it was very rare indeed that the eye moved to a location where stimulation was lacking on a particular trial, even though the location was highly probable in the overall sequence. The corresponding manual error response occured much more frequently. Another situation where the results demonstrate that the 'WHERE' system is automatic in its operation has been studied extensively by the author (Findlay, 1982). If, in a tracking or a search task, a subject is presented with two targets in neighbouring positions in peripheral vision, rather than a single target, the first movement of the eyes is a saccade which brings the gaze to an intermediate position between the targets. Loosely, it may be said that the eye is directed to the 'centre of gravity' of the configuration of targets. A further corrective saccade normally follows rapidly to bring the gaze accurately onto one target. This pattern occurs even when the subject is attempting to scan each target sequentially; the subject is unaware of the detailed pattern of his eye movements. This result, first reported by Coren and Hoenig (1972), has been termed the 'global effect' (Findlay, 1982) since it appears that it is the global properties of the stimulus which determine the spatial parameters of the saccade.

Figure 4 shows a simple situation in which the effect is observed. It is an extension of an earlier experiment (Findlay, 1981) in which subjects tracked a target moving in a sequence centre - periphery - centre - periphery - centre, etc. The average interval between steps was 600 msec, but the timing was made slightly irregular so that complete temporal predictability was absent. In the modified experiment, the peripheral target could take one of three possible forms : *a)* a single target either at 2 degrees right or 2 degrees left; *b)* a pair of targets, either both left or both right, at 2 degrees and 3 degrees; *c)* a pair of targets placed bilaterally, at 2 degrees right and at 2 degrees left. The subjects were instructed to track the spot as well as possible, and if two spots appeared, to fixate one of them. Figure 4 shows the global effect occurring in condition *b)*, when targets are presented at 2 and 3 degrees. The increase in amplitude in comparison with condition *a)*, the single 2 degrees target, is substantial and occurs without any marked increase in the variability of the saccade amplitudes. The results also suggest once again a dissociation between the programming of saccade amplitude and saccade latency. In the bilateral condition, with targets on both sides of the fixation point, the saccades are directed to one or the other target. Their amplitudes are not different from those of saccade to a single target. However the latencies are longer, by about 30 msec, than those in the other conditions. This result was found first by Lévy-Schoen (1969), who also showed (Lévy-Schoen, 1974) that the choice of which target receives fixation is determined princi-

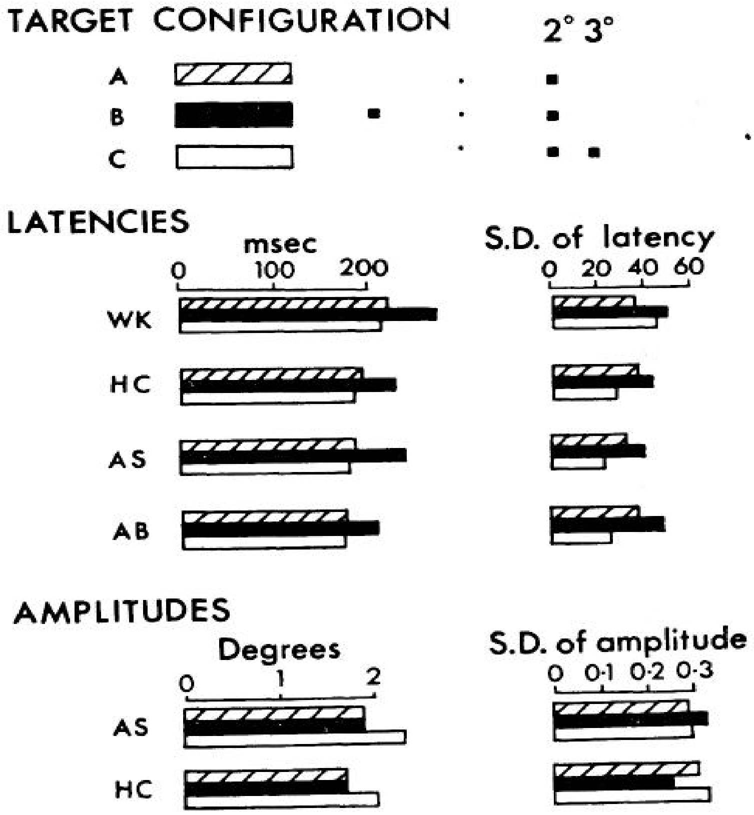

Fig. 4. — Results from an experiment involving rapid tracking of a target which alternated between a central location and a peripheral one. At the peripheral location, the target took one of the three forms shown at the top of the figure ; a single spot at 2 degrees eccentricity either left or right; two spots presented bilaterally at 2 degrees left and 2 degrees right; two spots presented at 2 degrees and 3 degrees, again either on the left or on the right. The subjects were instructed to track the spots, and if two spots appeared, to look at one of them. The lower figure shows latency data for four subjects and amplitude data for the two subjects whose calibrations were reliable. The amplitude data shows that for two targets on the same side of the fixation point, the first saccade is directed at an intermediate location between the targets (the global effect). (Figure redrawn from Findlay, 1983.)

pally by proximity to the fovea, a result since confirmed and extended (Findlay, 1980). In the unilateral condition, the pattern of results is the converse. Now the latencies of the first saccade are no different from those to a single target, but the amplitudes depend upon the stimulus configuration as discussed.

This experiment used targets which appeared with a sudden onset in the peripheral visual field. As discussed in the next section, the first saccade made to such targets invariably shows the global effect. However it may be argued that such a situation is not representative of normal viewing. Many situations in which saccades occur are when subjects are scanning an unchanging, static, field. There is surprisingly little

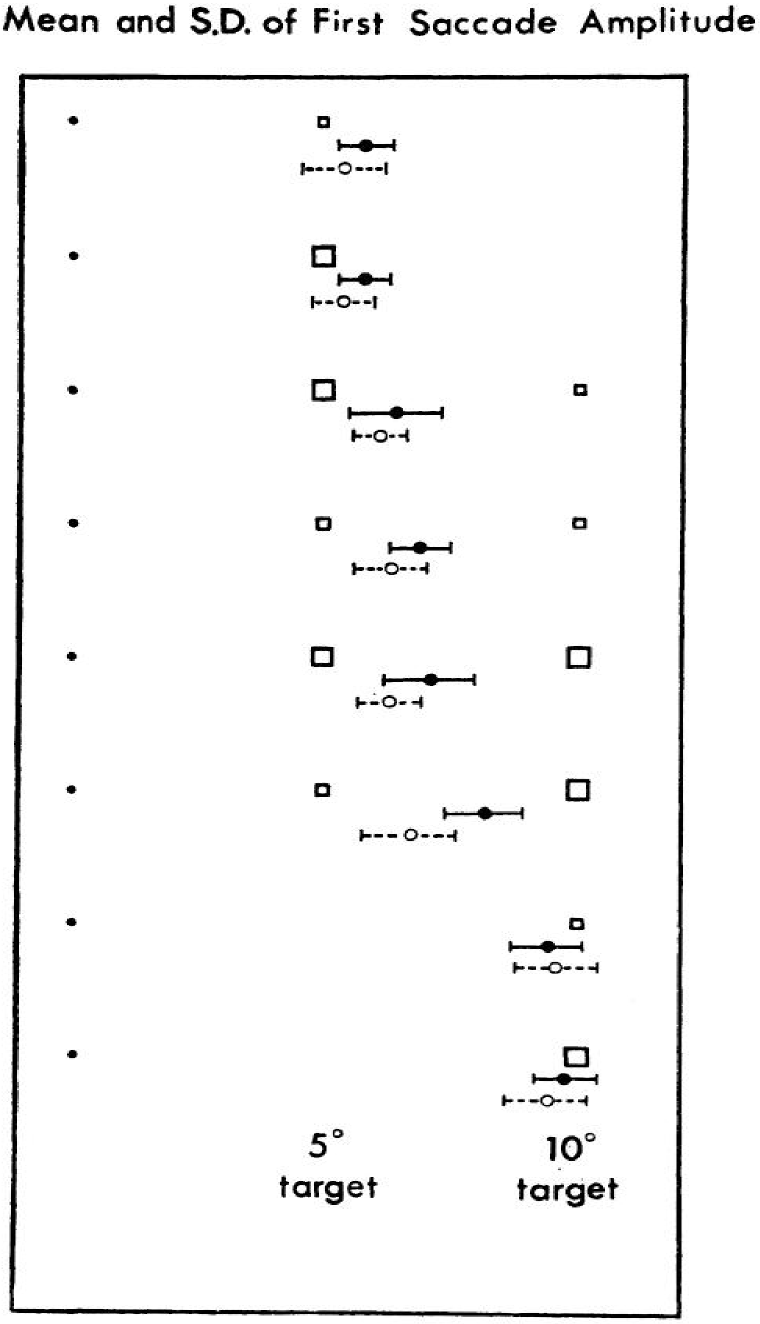

Fig. 5. — Saccade amplitudes from a study in which the subject fixated the central point and on each trial was presented with one of the eight possible stimulus configurations shown in the figure, which could either appear on the right or on the left. Filled circles show the mean and s.d. of the amplitudes of initial saccades resulting when the subject was asked to search for small gaps which could be present in the perimeter of the square. The open circles show corresponding data in a condition where the subject was required to ignore any gaps and indicate whether the stimulus configuration was the same as, or different from, that occurring on the previous trial. (Figure redrawn from Findlay, 1982.)

information about whether similar effects exist in this situation. Coren and Hoenig (1972) linked their finding to the dysmetric saccades noted when viewing the Muller-Lyer illusion (Yarbus, 1967), but the interpretation of this dysmetria is not straightforward (Festinger, White and Allyn, 1968). Data recently obtained by Z. Kapoula show that, in a scanning situation resembling reading, saccades may be programmed in a precise mode with long latencies, but subjects appear also to use a less precise mode and there is evidence that in this mode the global effect is present (Kapoula, 1982).

## MODIFIABILITY OF THE GLOBAL EFFECT

The global effect suggests that the amplitude of the initial saccade is determined by the properties of the peripheral stimulus. It is important to know to what extent this is true and to what extent scanning strategies or voluntary effort can modify this tendency to saccade to an intermediate position between two targets. A number of experiments will now be described which have have investigated this issue.

Figure 5 shows results from a study designed to test whether the global effect could be overcome by the scanning strategy used by the subject. In this experiment the subject had initially to fixate a central cross. When he released his finger from a button, a stimulus would appear consisting of either one or two squares. A small gap (3 min arc) was present in the perimeter of the displayed squares on one half of the trials. There were two experimental conditions. In the first, the subjects were asked to examine the squares and respond if there was a gap present. In the second, the subjects had merely to respond if the combination of squares (large-small, etc.) was identical to that which had been presented on the immediately prior trial. It was expected that the former condition (gap detection) would lead to more precise fixations on the target squares than the latter condition (comparison). The results in Figure 5 show that this did not prove to be the case. In both conditions, the global effect was found. There was a small but consistent difference between the conditions. Contrary to the predictions, in the gap detection condition the first saccade landed, on average, further from the individual targets. The first saccade was, of course, followed by further saccades which did take the eyes accurately to the individual targets. A point to note is that the size of the saccade is systematically influenced by the relative size of the target squares, showing that the term 'centre of gravity' is broadly appropriate, and that the effect can be attributed to processing in the sensory visual pathways.

Findlay and Crawford (1983) examined the effect of extended practice on the global effect. They used an experimental paradigm quite similar to that shown in Figure 5. However, the gap discrimination task was replaced by a task which involved a numerosity judgement about the

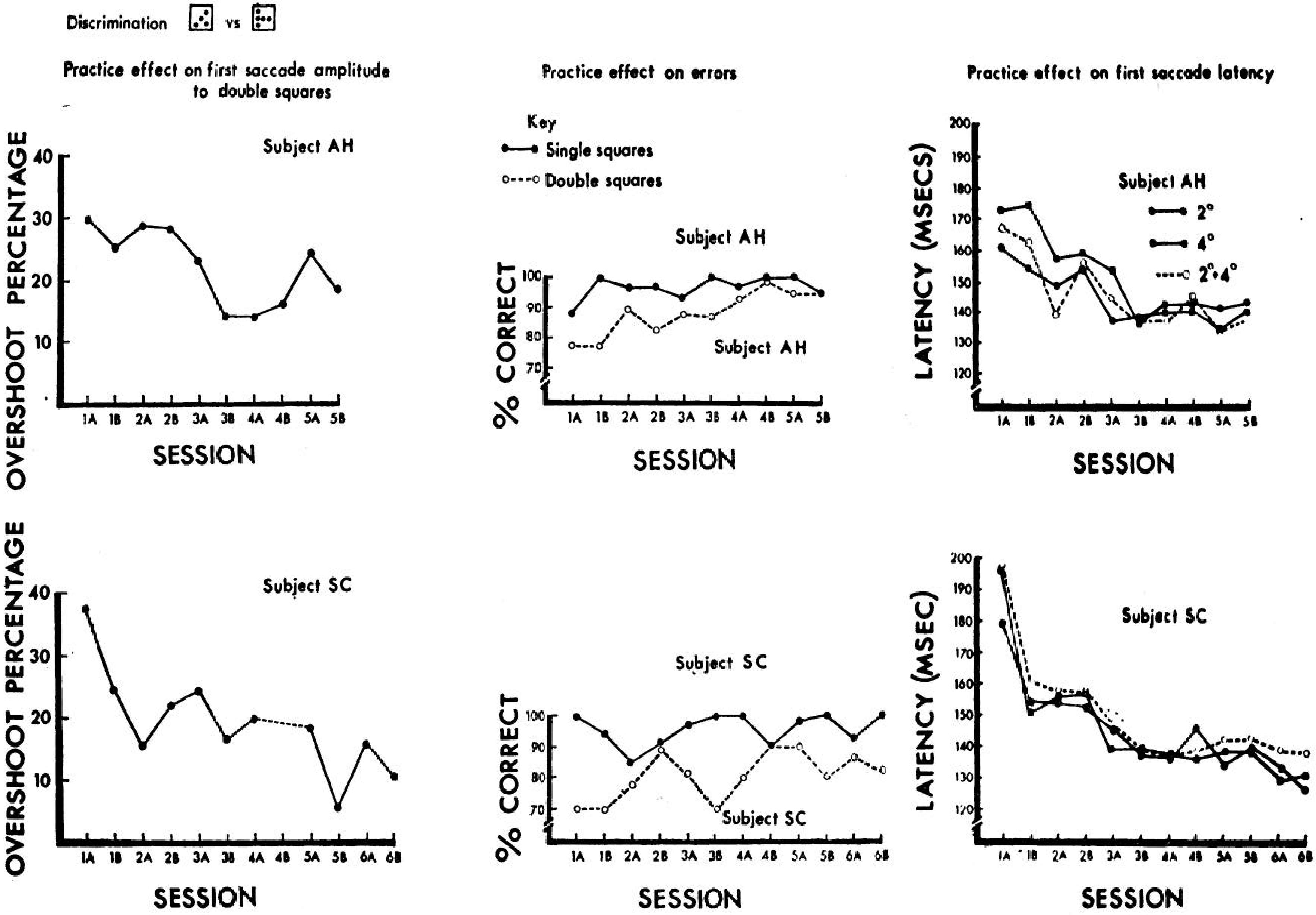

Fig. 6. — *Voir légende page ci-contre*

number of dots which were enclosed in each target (see Figure 6). This task could only be achieved when the eye fixated within about half a degree of the target. In this case, the global effect led the eye to a fixation position which was actually inappropriate for carrying out the task and the performance on the task showed a corresponding decrement. Over five days of practice sessions, two subjects both showed an ability to reduce, although never eliminate, the overshoot characteristic of the global effect (Figure 6).

A final experiment investigated the extent to which the global effect interacted with an existing scanning strategy. In this case the targets were letter pairs (with single letter configurations used as control). The pairs could either appear both on the same side of the original fixation position or else one member appeared on each side. In different experimental blocks the subjects were instructed either to report the letters from left to right or else from right to left. The results showed firstly that strategic influences almost always determine the direction of the saccade, provided that some visual stimulation occurs in the intended direction. When the presentation was bilateral, the first saccade was directed to left or to right depending on the instructions and was of the same magnitude as those to single targets. Only very occasionally was a reverse pattern seen in which the visual stimulation apparently dominated over the scanning strategy. Out of four subjects, one made 11 such saccades out of a total of 64, a second 3, and the remaining two subjects never showed reverse scanning.

However, stimulus factors proved to be of more significance in the determination of the amplitude of the saccade when two targets were

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Fig. 6. — *Détail de la légende de la figure ci-contre*

Data from a study in which two subjects were given extensive practice on a search and discrimination task involving one or two targets presented in peripheral vision. The targets were small squares containing four or five spots and the task of the subject was to report whether a five spot square had appeared.

*(a)* Practice effects on the programming of saccade amplitude. The graphs show the changes with practice in the magnitude of the global effect. This was evaluated by plotting the overshoot resulting in initial saccades to the double target configuration, with targets at 2 degrees and 4 degrees, in comparison with saccades to a single 2 degrees target. Each subject performed two blocks of 64 trials each on five (AH), or six (SC), successive days.

*(b)* Changes in error rate across the sessions for single and double targets.

*(c)* Changes in saccade latency with practice for the different target configurations. (Figure redrawn from Findlay and Crawford, 1983.)

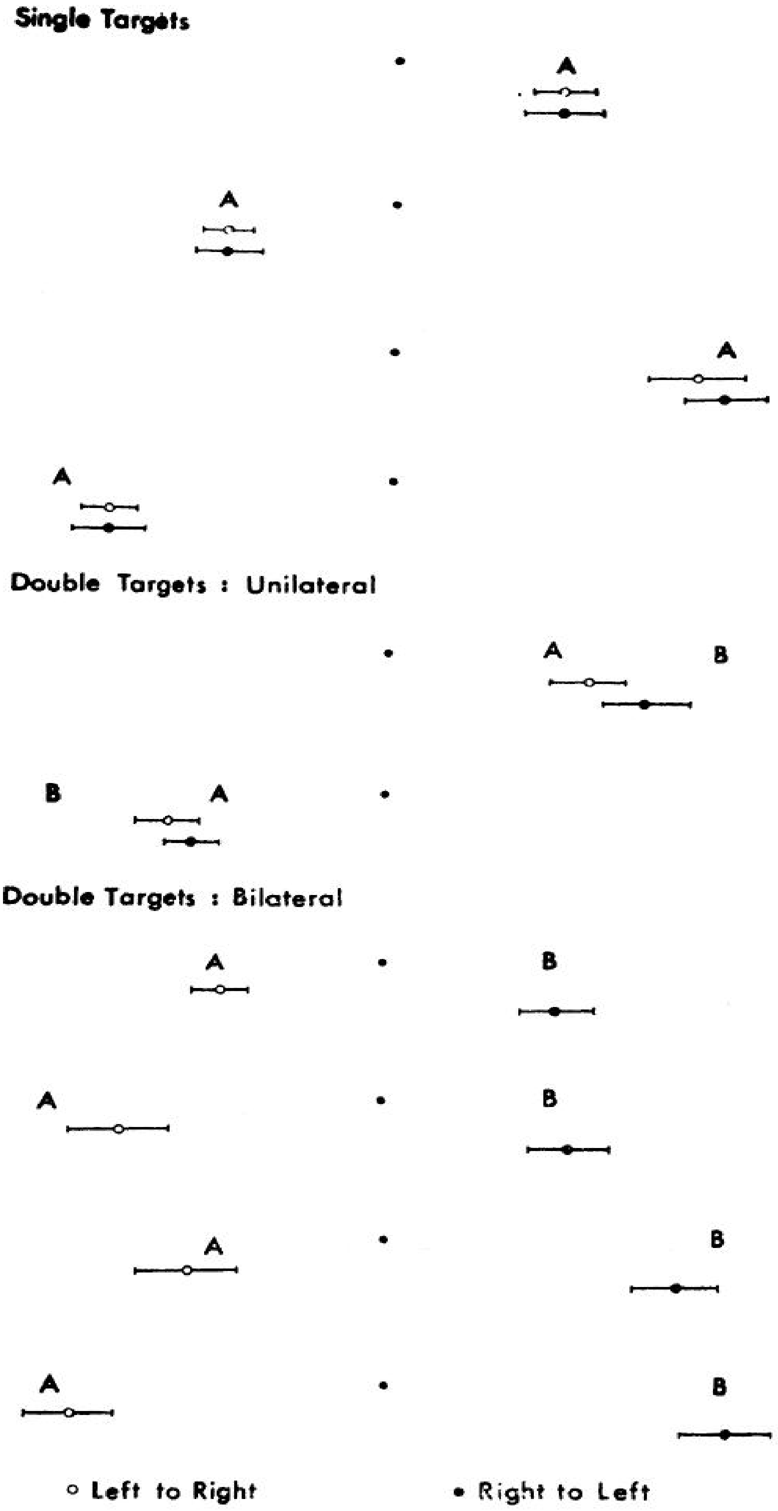

Fig. 7. — Results from an unpublished experiment to investigate the interaction of scanning strategies with the global effect. Four subjects were instructed to fixate the central point, following which there appeared a display consisting of either a single letter or a letter pair. The subject's task was simply to report the letter or letters with order of report specified (left-right or right-left) when two letters were presented. The letters appeared in various combinations of locations at 2 degrees and 4 degrees eccentricity, as shown. The data shown the mean location of the first saccades, together with the mean of the within block standard deviations. Four subjects were tested.

presented unilaterally. In this case, the global effect described above predicts an intermediate fixation in between the targets whereas the subject's volitional strategy is to aim for either the near or the far target. Thus stimulus factors are being set in opposition to volitional factors. Figure 7 shows the saccade end points. Although the scanning instructions clearly exerted an influence, it appears that is was not sufficient to allow complete freedom in selecting the saccade end point.

In all three experiments, the global effect was found, although the magnitude of the effect was influenced by the subject's strategy. Since the saccadic system is indisputably amenable to voluntary control, the existence of variability is less surprising than the fact that the magnitude of this variability is quite small. The global effect can perhaps be regarded as a 'default option' operating when no attention is specifically given by the subject to his eye positioning. This is then subject to some modification by attentional factors. The caution must again be made that all these results come from experiments in which information appears in the visual field with an abrupt temporal onset. In tasks such as reading, temporally changing information will certainly be present on the retina as a consequence of the previous pattern of saccadic movements. However it may be that a more elaborate form of processing, possibly involving saccadic suppression, allows a more precise direction of the eyes in these cases. This question requires detailed experimental investigation.

## SCANNING SACCADES WITH SYMBOLIC MATERIAL

We are now in a position to examine the generation of saccadic eye movements in more complex tasks. One feature of the saccadic system which has been demonstrated is the separation of amplitude and timing mechanisms. A result which might rather directly reflect this is the lack of correlation which frequently is found between measures of fixation amplitude and measures of fixation duration in reading tasks (Rayner, 1976).

In an earlier section it was shown that the instant at which a saccade is released is determined largely by non-specific factors such as the state of preparation of the subject. It is quite a small step to suppose that this nonspecific mechanism might be subject to control by the ongoing information processing undertaken by the subject. This appears to be borne out by the numerous studies which show that the duration of a fixation at a particular point in a visual task is related to the amount of information which needs to be processed at this point. A particularly clear demonstration comes from an experiment reported by Gould (1973). Subjects were asked to scan a set of alphabetic characters in order to find one which belonged to a previously memorised target set. The fixation duration on each item in this task, both target and non-target, was a linearly increasing function of the size of the target set. In this case, with equivalent sensory stimuli, the fixation duration is directly related to the amount of mental processing involved (size of the memory search set).

Many of a recent collection of papers presented at the conference on Eye Movements and Cognition (Fisher, Monty and Senders, 1981), operate the reasoning in the reverse direction and actually use the fixation time as an indicator of the processing difficulty at a particular location. Among the principal exponents of this logic have been Carpenter and Just. They have also extended the methodology to allow accumulation of the times of successive individual fixation within a word or symbol to form a measure of 'gaze duration'. There is no doubt that their work has led to fruitful analyses of a variety of tasks (mental rotation; Carpenter and Just, 1978; anaphoric reference, Just and Carpenter, 1978; reading, Just and Carpenter, 1980).

There does however appear to be a logical problem with this: it has been demonstrated that processing difficulty affects fixation duration, but not, of course, that this is the only factor to affect this measure. It is important to recognise clearly the various assumptions on which the use of fixation duration to index processing difficulty rests. Some of these are spelt out by the workers, others implicit. Firstly it is assumed that the eye remains fixated on a symbol as long as that symbol is being processed (the eye-mind assumption of Just and Carpenter, 1980). Secondly, it is assumed that only information from the immediate fixation region is analysed. Finally it is assumed that the fixation axis may be directed to the next processing location without additional demands on the cognitive system. It turns out that all these assumptions can be shown to be invalid on the basis of experimental evidence.

The first problem is that it is much too simplistic to consider only material immediately available in foveal vision when analysing oculomotor behaviour. Lévy-Schoen has carried out a series of experiments (Lévy-Schoen, 1981) in which the availability of peripheral information has been systematically varied in two ways. Firstly, stimuli are used which have different degrees of peripheral discriminability; secondly, a computer controlled 'saccade-contingent' method of presentation is employed, in which the aspects of a stimulus that are crucial for a perceptual discrimination are only presented when the saccade to the stimulus is detected, and so this information is never available in peripheral vision. The results of these experiments are unequivocal. It is always found that if peripheral information is available for processing during one fixation (F1), the fixation time at the next fixation (F2) decreases by an amount that increases with the amount of available information. Although one might expect the processing of peripheral information, when available, to lead to longer fixations at F1, rather intriguingly this is not the case. It appears that the benefit conferred by available peripheral information is not offset by corresponding costs in processing time.

The assumption that processing difficulty only affects the duration of the current fixation is also not completely valid, at least in the area of eye movements and reading. O'Regan (1981) measured fixation durations when subjects read prepared texts in which a linguistic change was made in some conditions in order to increase processing difficulty. The effect of this was that the increased difficulty produced longer fixations not just at the immediate fixation on the material (F1), but also on the following fixations F2 and F3 also.

The final assumption, that the oculomotor system can produce a saccade to the next peripheral location without additional demands on the processing system may also be of doubtful validity. The discussion of parallel processing given above emphasised that the hypothesized 'WHEN' system could be influenced by non specific factors, of a variety of types. Selection of a new fixation location in the periphery might be one of these. In some circumstances at least, accurate selection of fixation position does not occur. This is the case in the experiments on the global effect described above and another striking example is the recent study of Viviani and Swensson (1982), where it was shown that fixations in a search task often landed at some distance from a designated target position. Kapoula (1982, 1983) has claimed that accurate fixation can normally only by achieved at the expenses of longer fixation pauses; a form of speed-accuracy trade-off.

Some effort has been devoted to finding how readily information in the periphery of vision can be used in the control of eye movements during visual search. In an early study, Williams (1967, 1973) asked subjects to search for a target in a cluttered array of objects of varying shapes, sizes, and colours. The object of his studies was to examine the extent to which advance information about target characteristics would aid search. He measured search times and also examined in detail the degree to which fixations prior to the fixation on the target were aided by the advance information. He found that the two measures corresponded, that is advance information which speeded search times was also effective in constraining fixations to be on targets of the appropriate specifications. However subjects demonstrated severely limited capacities to take advantage of the advance information. Advance information about shape could not be used; information about size was of very little value, and only information about colour was really helpful. This finding has evident applications in the use of colour coding in complex display and control panels.

A full account of scanning eye movements must therefore also involve consideration of the processing of information in the visual periphery. How can this be done? One approach has originated mainly from workers in the Netherlands, who have developed Mackworth's (1965) concept of the 'useful field of view'. Engel (1971, 1974) defined the term 'conspicuity area' as the area of the visual field around the point of fixation within which a discrimination could be made of a target embedded in a set of non-target items. He showed that it was dependent on the details of the discrimination, the density and regularity of the non-target items, and finally on the subject's voluntary covert attentional processes. Bouma used a similar concept which he termed 'functional field of view', and related this to reading performance (Bouma, 1978). He defines the functional field of view as the area of the visual field from which one can see an object in a single eye pause.

Characteristically, the useful field of view possesses a central region in which the discrimination can be made perfectly and this is surrounded by a region, often of considerable extent, in which psychophysical measures show imperfect, but above chance, discrimination performance. These areas depend not just upon the details of the target to be discriminated, but they are also strongly dependent upon any other stimulation close by in the visual field. This 'lateral masking' effect may well account for the inability to use shape information in the experiments of Williams described above. A capacity, albeit a weak one, to guide saccadic eye movements on the basis of shape information has been demonstrated by Gould and Dill (1969). They showed that quite small differences in peripheral contour could be used to guide immediate saccadic responses. The differences in shape were more subtle than those that the subjects in the Williams task were unable to make use of, and it suggests the cluttered nature of the displays in the task used by Williams was principally responsible for the problem.

Precise positioning of the eye to a desired peripheral location may thus often be difficult, or even impossible. An immediately related question concerns the perceptual costs of off target fixations. Under what circumstances is it advantageous to direct the eye precisely on to a target? This question has been examined for the off target fixations that arise as a consequence of the global effect. In the experiments described in Findlay (1982), the useful field of view of the targets was comparatively large and no deleterious consequences of the off target fixations could be found. However when care was taken to choose a task with a very small useful field of view, then performance deterioration did occur (Findlay and Crawford, 1983). The current work of O'Regan addresses a similar question for word recognition (O'Regan, 1981). He finds that fixation position within a letter string constituting a word has a surprisingly large effect on the naming time for the word. Some of this is attributable to the need for a second fixation in cases when the initial fixation is too far from the centre, but substantial effects occur apart from this.

## SACCADES AND PICTORIAL MATERIAL

In the previous section, the relationship between eye movement activity and perceptual performance has been studied for tasks involving discrete and isolated visual elements. Not surprisingly, these constitute the type of situation most amenable to analysis. However, some attempts have been made to understand how eye movements are used when viewing more complex visual material. Records such as those of Buswell (1935) and Yarbus (1967) have always possessed considerable appeal. An idea which gained prominence in the early seventies was that of the scanpath. Noton and Stark (1971*a*, 1971*b*) in an influential, but rather premature, set of papers claimed that when a particular pattern is viewed, there is a particular sequence of eye movements elicited, and this sequence is important in accessing that pattern in memory. Some years ago we designed a study to test this idea (Walker-Smith, Gale and Findlay, 1977). We used face photographs, reasoning that different faces possess the same overall contour configuration and thus might elicit such regular scanning sequences.

The design was that a set of similar faces was chosen (such a use of similarity of course already introduces a subjective element into the experimental situation). The subject was asked to memorise one face and, following this, to make a two-choice judgement as to whether subsequently presented faces were the same as, or different from, the target face. The scanning eye movements of the subject were recorded, using the oculometer technique whereby the position of the corneal reflex of infra red marker lights is assessed relative to the centre of the pupil.

Figure 8 shows the scanning patterns recorded from three subjects. We wished to make objective the idea of a 'scanpath' but this presented several difficulties. I have argued earlier in this article reasons for supposing that oculomotor control is unlikely to be extremely accurate. Consequently a relatively lax set of criteria were adopted. We simply divided the face into four regions, defined as the regions surrounding the principal features (mouth, nose, left eye, right eye). The scanning sequence between these regions was noted, saccades within a region being regarded as corrective saccades and thus ignored (the number of such saccades turned out to be fairly small). We found with this criterion that on a surprisingly high proportion of the trials, a subject would repeat a particular scanning pattern. The actual sequence was different for each individual subject. The proportion of trials on which such sequences occurred was about 60 per cent. This is comparable to that found in the original study of Noton and Stark (1971) and also by other workers who have looked for scanpaths.

If the scanpath is playing an important part in the perceptual process,

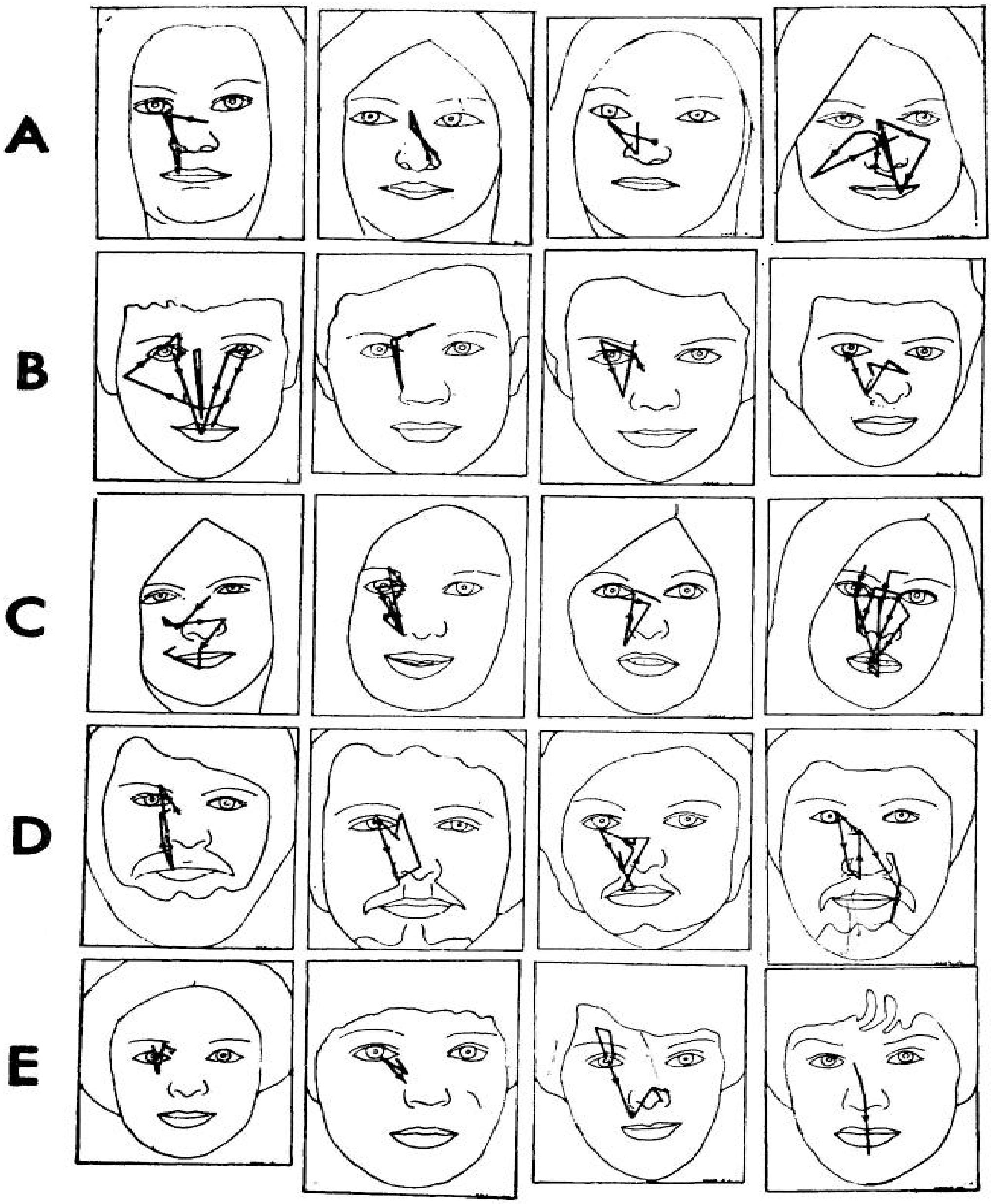

Fig. 8. — Scanning patterns of three subjects in a facial recognition task. Five sets of face photographs (A-E) were chosen on the basis of similarity of overall outline. For each set, the subject first viewed a target face for 10 seconds. Following this, the subject was presented with a sequence or test faces, which might or might not include a repetition of the target face, and for each face was required to make a same/different decision. The eye scan pattern during this decision process was recorded and is shown by the heavy line in the figure. The three blocks show data from the three individual subjects tested. (Figure redrawn from Waker-Smith, Gale and Findlay, 1977.)

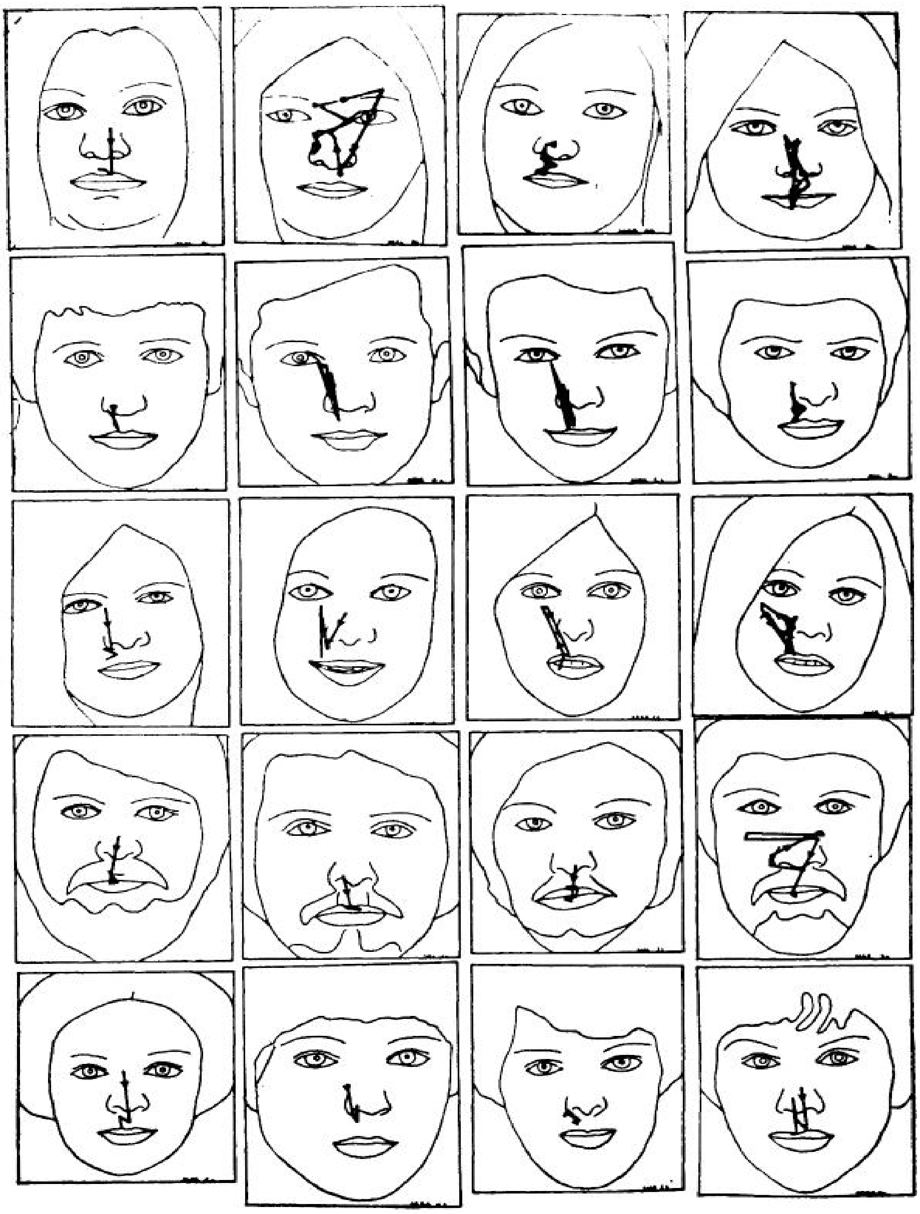

Fig. 8 *(suite)*

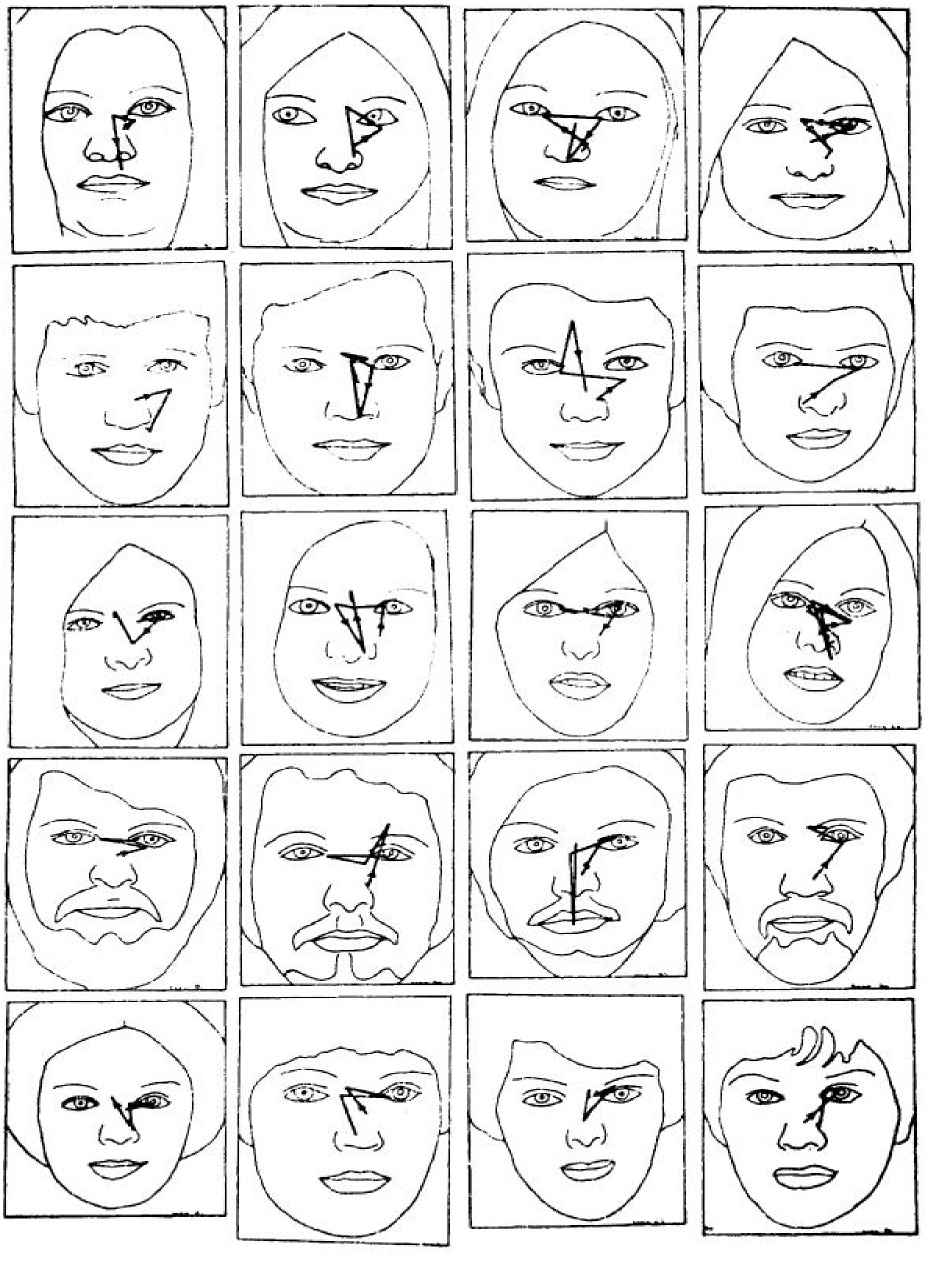

**Fig. 8** ***(suite et fin)***

we argued that trials with scanpaths should result in improved performance. In our task, accuracy was close to 100 per cent; however, we also took a measure of the response latency. All the subjects showed longer response latencies on trials in which the regular sequence was absent than on those for which it was present. This would appear to provide encouragement for the scanpath hypothesis. However, in a second experiment we showed that the existence of scanpaths is dependent on the situation and is certainly not a necessary aspect of face viewing. In this case we presented two faces side by side and asked the subject to make a same/different judgement. If the scanpath was an integral part of the perceptual process, then we might expect that subjects would scan one face in its entirety and then pass to the second. In fact, we observed a very different form of oculomotor behaviour. The subjects all adopted a strategy of making several large saccades between the faces and scanning within an individual face occurred quite rarely. This shows that the eye movement strategy is contingent on the ongoing cognitive activity. In the simultaneous comparison task, it was evident that the demands of the comparison process were exerting much more

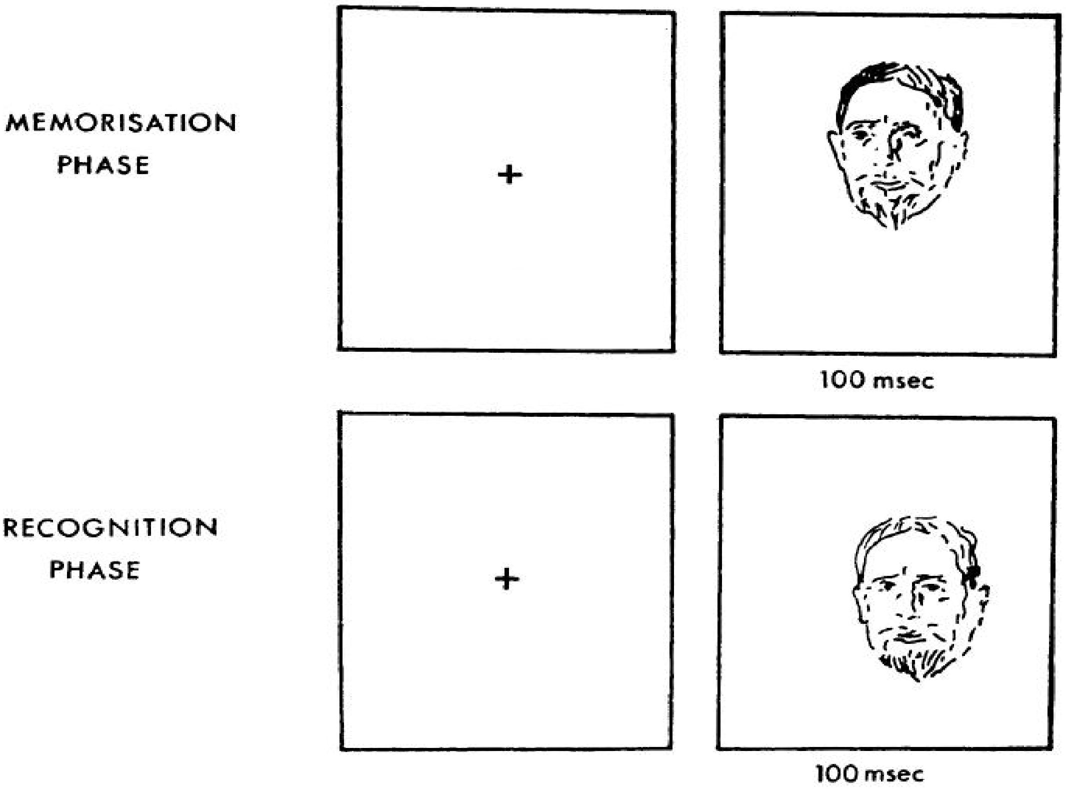

Fig. 9. — Plan of experiments to investigate the importance of fixation location in face recognition. In the memorisation phase, subjects viewed a brief exposure of a face with fixation controlled to be either on the eye or on the mouth. In the recognition phase, a similar presentation was given with either the same or the alternative fixation location.

influence on the eye movement behaviour than any scanpath programme.

One question often brought up in connection with this type of study is the extent to which eye movements are, in fact, necessary in order to perform the task. We have recently been attempting to provide an answer to that question and furthermore to establish how important it might be to direct fixation to a particuler location when viewing faces. Once again we used face photographs and the design is shown in Figure 9. During the memorisation period, the subjects viewed face photographs in a tachistoscope with fixation constrained at one particular position (either the eye or the mouth) on the face. The subject was then asked to make a same/different judgement when a second similar face was viewed in a tachistoscopic exposure with either the same fixation position or an altered position. We used fixation positions located on either eye or mouth and thus had four conditions (initial fixation eye—comparison fixation eye; initial fixation eye—comparison fixation mouth; initial fixation mouth—comparison fixation eye; and initial fixation mouth—comparison fixation mouth).

The results (Stockton, 1981) showed that there were no significant main effects of fixation position of any sort on the response times. However some interesting effects did emerge on response accuracy.

These are shown in Table 1. In spite of careful preselection of faces matched to be as similar as possible, we found that accuracy was extremely high with only a few percent errors. Nonetheless the distribution of errors was systematic. More errors occurred when the fixation position changed between memorisation and recognition phases, than when it remained the same. These results show that much, but not all, of the information contained in a face is available to the subject in a single fixation, and, from our explorations so far, is available wherever fixation happens to fall. The highest spatial resolution of foveal vision is not necessary to extract this, so accurate eye fixations are not required. However, observers do derive some benefit from moving their eyes to the favoured positions such as the mouth or eyes of the target faces.

Although no full theoretical treatment of picture perception has yet been made, I believe that a promising approach is the 'frame' theory of Minsky (1975). Some of the results of these experiments can be accommodated within this. In its most general formulation, a 'frame' is a way of representing knowledge and consists of an ordered graph structure with particular pieces of information being located at the nodes. It is assumed that mental representations, either abstract or tied to specific sense modalities, are of this form. Friedman (1979) has given a clear account of the way this might apply to pictorial perception and two concepts are critical. Firstly, a frame structure may often be hierarchical with frames at one level acting as subframes for those at the next level of the hierarchy. Thus, for example, the general concept of a person

**TABLE 1**

Experiment 1

| | | Position at memorisation | |
|---|---|---|---|
| | | Eye | Mouth |
| Position at Test | Eye | 12.4 | 26.4 |
| | Mouth | 14.4 | 9.2 |

Experiment 2

| | | Position at memorisation | | |
|---|---|---|---|---|
| | | Left Eye | Right Eye | Mouth |
| Position at Test | Left Eye | 6.7 | 2.5 | 7.5 |
| | Right Eye | 7.5 | 9.2 | 15.0 |
| | Mouth | 5.0 | 15.8 | 6.7 |

Table 1. Results from two experiments examining facial recognition with briefly presented material. Subjects were given a 100 ms presentation of a photograph of an unfamiliar face with their fixation position aligned with one of the features. Immediately afterwards they were given a set of recognition tests, of either the identical face or a closely similar one. Again fixation position was controlled as shown. The subject was required to make a two choice button press response indicating whether the face was identical to, or different from, that previously memorised. The figures show percentage recognition errors. (Experiment 1: 5 subjects, 10 test faces, 60 recognition faces; Experiment 2: 12 subjects, 9 test faces, 36 recognition faces.)

Experiment 1 used a tachistoscopic presentation in which the faces were always aligned centrally and the position of the fixation point varied. Experiment 2 was a replication but a video technique of presentation was used in which the subject always saw a central fixation point and the relative position of the faces was varied.

might be represented as a frame. For the purposes of visual representation, this would have a subnode of a face, together with other subnodes for arms, legs, etc. In turn, the face node could be classified as a frame with subnodes corresponding to eyes and mouth. Secondly it is assumed that high levels of the hierarchy can be accessed readily without necessarily involving the subnodes. When this happens, the more detailed levels will have default, i.e. general, labelling unless and until instantiation occurs in any particular case. For example the general 'face' frame might default to a neutral clean shaven representation, but in any particular instantiation could acquire a setting for 'bearded'. Likewise the general face frame would not contain specific detail about eye characteristics until this was instantiated.

It seems plausible that such a theory could be worked out in detail to account for the results of the tachistoscopic presentation experiments. Moreover, saccadic eye movements then fulfil a very obvious role and with some reasonable additional assumptions, it becomes possible to account for the observed patterns of eye movements. The suggestion would be that the general framework can in some way be accessed at the first fixation, and then the details provided by successive saccades allow a gradually more complete instantiation to emerge. It must be presumed that a number of frameworks exist for different facial types. If the further assumption is made that the different features constituting subnodes of the face frame had different priorities, and furthermore that information about such priorities was available to guide the scanning process, the scanpath then is interpretable as a progression down a priority hierarchy. In general the priorities would be expected to coincide closely with the information available in the different features, but there would be scope for individual variations here, particularly when two subnodes both contained much information.

This would account for a significant finding in the Walker-Smith *et al.* (1977) study. When we compared the fixation patterns in the sequential comparison task with those in the simultaneous comparison task, we found that each subject distributed their fixations amongst the different features in a similar way in the two tasks. This can be understood if it is assumed that the priority hierarchy of the features is different for the different subjects. In the single face scans, successive fixations are directed in order of priority down the hierarchy. With the simultaneous presentation, the feature hierarchy ineracts with the comparison process, leading to the observed eye scans from one face to the other.

## CONCLUSION

This article commenced by reviewing work on saccades in tracking and acquisition tasks with very simple targets. Two results were emphasized. Firstly, factors controlling the latency of the saccade were dissociated from those controlling its spatial characteristics, and particularly its amplitude. This led to an account of parallel processing models of saccade generation which can now be formulated with considerable precision. The second result concerned solely the spatial characteristics of saccades and it was shown that saccade amplitudes appear to be calculated on the basis of global stimulus information, at least when saccading to a target newly appearing in the visual field. Experiments were described in which this result was used as an indicator for the interaction of sensory and central factors in the programming of saccades.

The implications of these processes were developed for the situation when an observer scans a series of discrete stimulus elements. A detailed analysis was made of the proposition that saccade fixation pause times provide an index of perceptual processing load. While this approach finds support from basic studies, it was suggested that two aspects of peripheral processing could not be neglected. Perceptual processing of peripheral material would facilitate later central processing of the same material and consequently reduce fixation times, and secondly, processing would also be necessary to direct the next saccadic movement. The final topic considered was scanning saccades with more complex and unified pictorial material. Although no rigorous theories have yet been developed in this area, it was suggested that frame theory might provide a way forward.

The wide ranging nature of this discussion is a reflection of the topic, which forms a microcosm of experimental psychology, linking neurophysiology at one extreme with semantic theories of cognition at the other. It is an exciting field, with progress being made rapidly across this range. Many gaps in our understanding exist, but we can say with confidence that these will gradually be filled if experimental and theoretical progress continues at its current rate.

## *SUMMARY*

*This article concentrates on the human saccadic eye movement and examines its interest for psychologists both as an individual behavioural response and as a component of more complex perceptual behaviour. Research is reviewed which examines single saccades to targets in the visual periphery. This suggests a parallel processing model in which separate processes determine firstly the latency of the saccade and secondly its spatial components. The global effect is described whereby the amplitude of a saccade to an extended peripheral target depends upon the global properties of the target. Experiments show how this may be used to study the interaction of sensory and volitional factors in the production of saccades. Progressing to more complex material, various extra considerations are described relating to saccades produced when scanning sequences of symbols and text. This leads finally to a discussion of saccades when viewing pictorial material.*

*Key words : saccadic eye movements, peripheral vision, visual scanning.*

## BIBLIOGRAPHY

Bach-y-Rita (P.), Collins (C. C.), Hyde (J. E.) — *The control of eye movements*, New York, Academic Press, 1971.

Bahill (A. T.), Adler (D.), Stark (L.) — Most naturally occurring saccades have magnitudes of 15 degrees or less, *Investigative Ophthalmology*, 1975, *14*, 468-469.

Baker (R.), Berthoz (A.) (Edit.) — *Control of gaze by brain stem neurons*, Amsterdam, Elsevier North Holland, 1977.

Barnes (G. R.) — Vestibulo-ocular function during co-ordinated eye and head movements to acquire targets, *Journal of Physiology*, 1979, *287*, 127-147.

Becker (W.), Jürgens (R.) — An analysis of the saccadic system by means of double step stimuli, *Vision Research*, 1979, *19*, 967-983.

Biederman (I.) — On the semantics of a glance at a scene, *in* M. Kubovy and J. R. Pomerantz (Edit.), *Perceptual Organization*, Hillsdale (NJ), Lawrence Erlbaum, 1982, 213-253.

Bouma (H.) — Visual search and reading: eye movements and the functional visual field, *in* J. Requin (Edit.), *Attention and Performance VII*, Hillsdale (NJ), Lawrence Erlbaum, 1978, 115-147.

Buswell (G. T.) — *How people look at pictures*, Chicago, Chicago University Press, 1935.

Carpenter (P. A.), Just (M. A.) — Eye fixations during mental rotation, *in* J. W. Senders, D. F. Fisher and R. A. Monty, *Eye movements and the higher psychological functions*, Hillsdale (NJ), Lawrence Erlbaum, 1978, 115-133.

Cohen (M. E.), Ross (L. E.) — Saccade latency in children and adults: effects of warning interval and target eccentricity, *Journal of Experimental Child Psychology*, 1977, *23*, 539-549.

Coren (S.), Hoenig (P.) — Effect of non-target stimuli upon length of voluntary saccades, *Perceptual and Motor Skills*, 1972, *34*, 499-508.

Engel (F. L.) — Visual conspicuity, directed attention and retinal locus, *Vision Research*, 1971, *11*, 563-576.

Engel (F. L.) — Visual conspicuity and selective background interference in eccentric vision, *Vision Research*, 1974, *14*, 459-471.

Festinger (L.), White (C. W.), Allyn (M. R.) — Eye movements and decrements in the Muller-Lyer illusion, *Perception and Psychophysics*, 1968, *3*, 376-382.

Findlay (J. M.) — The visual stimulus for saccadic eye movements in human observers, *Perception*, 1980, *9*, 7-21.

Findlay (J. M.) — Spatial and temporal factors in the anticipatory generation of saccadic eye movements, *Vision Research*, 1981, *21*, 347-354.

Findlay (J. M.) — Global processing for saccadic eye movements, *Vision Research*, 1982, *22*, 1033-1045.

Findlay (J. M.) — Visual information processing for saccadic eye movements, A. Hein and M. Jeannerod (Edit.), *Spatially co-ordinated behaviour*, New York, Berlin, Springer-Verlag, 1983, 281-303.

Findlay (J. M.), Crawford (T. J.) — The visual control of saccadic eye movements : evidence for limited plasticity, *in* R. Groner, C. Menz, D. F. Fisher and R. A. Monty (Edit.), *Eye movements and psychological processes : international perspectives*, Hillsdale (NJ), Lawrence Erlbaum, 1983, 115-127.

Fisher (D. F.), Monty (R. A.), Senders (J. W.) (Edit.) — *Eye movements : cognition and visual perception*, Hillsdale (NJ), Lawrence Erlbaum, 1981.

Friedman (A.) — Framing pictures: the role of knowledge in automatized encoding and memory for gist, *Journal of Experimental Psychology: General*, 1979, *108*, 316-355.

Frost (D.), Pöppel (E.) — Different programming modes of human saccadic eye movements as a function of stimulus eccentricity: indications of a functional subdivision of the visual field, *Biological Cybernetics*, 1976, *23*, 39-48.

Fuchs (A. F.), Becker (W.), Edit.), — *Progress in oculomotor research*, Amsterdam, North-Holland Elsevier, 1981.

Gorea (A.), Findlay (J. M.), Lévy-Schoen (A.) — *Changing attention along the horizontal meridian; a study of oculomotor latencies*, Paper presented at the AVA Meeting on Eye Movements and Vision, Durham, March 1980.

Gould (J. D.) — Eye movements during visual search and memory search, *Journal of Experimental Psychology*, 1973, *98*, 184-195.

Gould (J. D.), Dill (A. D.) — Eye movement parameters and pattern discrimination, *Perception and Psychophysics*, 1969, *6*, 311-320.

Heywood (S.), Churcher (J.) — Structure of the visual array and saccade latency: implications for oculomotor control, *Quarterly Journal of Experimental Psychology*, 1980, *32*, 335-341.

Just (M. A.), Carpenter (P. A.) — A theory of reading: from eye fixations to comprehension, *Psychological Review*, 1980, *87*, 329-354.

Just (M. A.) and Carpenter (P. A.) — Inference processes during reading: reflections from eye fixations, *in* J. W. Senders, D. F. Fisher and R. A. Monty, *Eye movements and the higher psychological functions*, Hillsdale (NJ), Lawrence Erlbaum, 1978, 157-173.

Kapoula (Z.) — *Le contrôle des mouvements des yeux : information périphérique et modes d'explorations des alignements graphiques*, Thèse de 3$^{e}$ cycle, Université Paris V, 1982.

Kapoula (Z.) — The influence of peripheral preprocessing in oculomotor programming in a scanning task, *in* R. Groner, C. Menz, D. F. Fisher et R. A. Monty (Edit.), *Eye movements and psychological processes: international perspectives*, Hillsdale (NJ), Lawrence Erlbaum, 1983, 101-114.

Lennestrand (G.), Bach-y-Rita (P.) (Edit.) — *Basic mechanisms of ocular motility*, Oxford, Pergamon Press, 1975.

Lévy-Schoen (A.) — Détermination et latence de la réponse oculomotrice à deux stimulus, *L'Année Psychologique*, 1969, *69*, 373-392.

Lévy-Schoen (A.) — Le champ d'activité du regard : données expérimentales, *L'Année Psychologique*, 1974, *74*, 43-66.

Lévy-Schoen (A.) — Flexible and/or rigid control of oculomotor scanning behavior, *in* D. F. Fisher, R. A. Monty and J. W. Senders (Edit.), *Eye movements: cognition and visual perception*, Hillsdale (NJ), Lawrence Erlbaum, 1981, 299-314.

Lévy-Schoen (A.), Blanc-Garin — On oculomotor programming and perception, *Brain Research*, 1974, *71*, 443-450.

McIlwain (J. T.) — Large receptive fields and spatial transformations in the visual system, *in* R. Porter (Edit.), *International Review of Physiology, Volume 10, Neurophysiology II*, 1976, 223-248.

Mackworth (N. F.) — Visual noise causes tunnel vision, *Psychonomic Science*, 1965, *3*, 67-68.

Marr (D.) — *Vision*, San Francisco, Freeman, 1982.

Matin (E.) — Metacontrast and saccadic suppression, *Psychological Review*, 1975, *82*, 451-461.

Mays (L. E.), Sparks (D. L.) — Saccades are spatially, not retinotopically coded, *Science*, 1980, *211*, 1163-1165.

Michard (A.), Têtard (C.), Lévy-Schoen (A.) — Attente du signal et temps de réaction oculomoteur, *L'Année Psychologique*, 1974, *74*, 387-402.

Minsky (M.) — A framework for representing knowledge, *in* P. H. Winston (Edit.), *The psychology of computer vision*, New York, McGraw-Hill, 1975.

Noton (D.), Stark (L.) — Scanpaths in eye movements during pattern perception, *Science*, 1971 *a*, *171*, 308-311.

Noton (D.), Stark (L.) — Scanpaths in saccadic eye movements whilst viewing and recognising patterns, *Vision Research*, 1971 *b*, *11*, 929-942.

O'Regan (K. J.) — The convenient viewing position hypothesis, *in* D. F. Fisher, R. A. Monty and J. W. Senders (Edit.), *Eye movements: cognition and visual perception*, Hillsdale (NJ), Lawrence Erlbaum, 1981, 289-298.

Posner (M. I.) — Orienting of attention, *Quarterly Journal of Experimental Psychology*, 1980, *32*, 3-25.

Posner (M. I.), Nissen (M. J.), Ogden (W. C.) — Attended and unattended processing modes: the role of set for spatial location, *in* H. L. Pick and I. J. Saltzman (Edit.), *Modes of perceiving and processing information*, Hillsdale (NJ), Lawrence Erlbaum, 1978, 137-157.

Rashbass (C.) — The relationship between saccadic and smooth tracking eye movements, *Journal of Physiology*, 1961, *159*, 326-338.

Rayner (K.) — What guides a reader's eye movements? *Vision Research*, 1976, *16*, 829-837.

Regan (D.) — Visual information channeling in normal and disordered vision, *Psychological Review*, 1982, *89*, 407-444.

Riggs (L. A.), Merton (P. A.), Morton (H. B.) — Suppression of visual phosphenes during saccadic eye movements, *Vision Research*, 1974, *14*, 997-1010.

Robinson (D. A.) — The mechanics of human saccadic eye movement, *Journal of Physiology* (London), 1964, *174*, 245-264.

Robinson (D. A.) — Eye movements evoked by collicular stimulation in the alert monkey, *Vision Research*, 1972, *12*, 1795-1808.

Ross (L. E.), Ross (S. M.) — Saccade latency and warning signals: stimulus onset, offset and change as warning events, *Perception and Psychophysics*, 1980, *27*, 251-257.

Saslow (M. G.) — Effects of components of displacement step stimuli on latency for saccadic eye movements, *Journal of the Optical Society of America*, 1967, *57*, 1024-1029.

Schiller (P. H.), Koerner (F.) — Discharge characteristics of single units in superior colliculus of adult rhesus monkey, *Journal of Neurophysiology*, 1971, *34*, 920-936.

Senders (J. W.), Fisher (D. F.), Monty (R. A.) (Edit.) — *Eye movements and the higher psychological functions*, Hillsdale (NJ), Lawrence Erlbaum, 1978.

Spady (L. A. Jr.) — *Airline pilot scanning behaviour during approaches and landing in a Boeing 737 simulator*, AGARD Conference Proceedings No. 240, 1978.

Sternberg (S.) — The discovery of processing stages: extension of Donders' method, *in* W. G. Koster (Edit.), *Attention and Performance II, Acta Psychologica*, 1969, *30*, 276-315.

Stockton (H. M.) — *Face perception without eye movement*, Bachelor of Science Dissertation, University of Durham, 1981.

Van Gisbergen (J.) Robinson (D. A.) — Generation of micro- and macrosaccades by burst neurons in the monkey, *in* R. Baker and A. Berthoz, *Control of gaze by brain stem neurons*, Amsterdam, Elsevier North Holland, 1977.

Van Gisbergen (J.), Gielen (S.), Cox (H.), Bruijns (J.), Schlaars (H. K.) — Relation between metrics of saccades and stimulus trajectory in visual target tracking; implications for models of the saccadic system, *in* A. F. Fuchs and W. Becker, *Progress in oculomotor research*, Amsterdam, North Holland Elsevier, 1982, 19-27.

Viviani (P.), Swensson (R. G.) — Saccadic eye movements to peripherally discriminated human targets, *Journal of Experimental Psychology: Human Perception and Performance*, 1982, *8*, 113-126.

Walker-Smith (G. J.), Gale (A. G.), Findlay (J. M.) — Eye movement strategies involved in face perception, *Perception*, 1977, *6*, 313-326.

Williams (L. G.) — The effects of target specification on objects fixated during visual search, *in* A. F. Sanders (Edit.), *Attention and Performance, Acta Psychologica*, 1967, *27*, 355-360.

Williams (L. G.) — Studies of extrafoveal discrimination and detection, *in* NRC Committee on vision (Edit.), *Visual Search*, Washington, National Academy of Sciences, 1973, 77-92.

Wurtz (R. H.), Albano (J. E.) — Visual motor function of the primate superior colliculus, *Annual Review Neuroscience*, 1980, *3*, 189-226.

Yarbus (A. L.) — *Eye movements and vision* (Translation from the Russian edited by L. A. Riggs,) New York, Plenum Press, 1967.

Zee (D. S.), Optican (L. M.), Cook (J. D.), Robinson (D. A.), Engel (W. L.) — Slow saccades in spinocerebellar degeneration, *Archives of Neurology*, 1976, *33*, 243-251.

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