EVENT PERCEPTION AND SENSORY STORAGE

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ABSTRACT

The experiments studied the ability to perceive visual events of a very simple kind: the appearance and disappearance of isolated dots in random dot patterns. The aim of the investigation was to explore the limits of this ability and clarify the relationship between event perception and sensory storage.

The first series of experiments studied the ability to detect the appearance and disappearance of single dots. Under appropriate conditions such changes can be detected in a pattern containing 1024 dots with 98% accuracy. This level of accuracy was largely maintained over manipulation of the number of dots in the pattern, pattern size and separation between dots. Performance was unaffected by whether pattern luminance was uniform or not. It is argued that to explain this performance the notion of sensory integration must be augmented by the concept of sensory differentiation. The ability to detect events was further investigated as a function of pattern complexity and ISI. The storage underlying event detection has a very high capacity and a short duration.

The second series of experiments investigated the ability to perceive patterns of events. Letters defined by either appearances or disappearances were accurately identified; thus a pattern which was not visible was made visible by its disappearance. A measure of localization was obtained by requiring subjects to judge whether three events were aligned. It is concluded that both onset and offset of a pattern convey information about form but that acuity for events is poorer than for sustained stimuli. The possibility that event perception is achieved by integration at short stimulus durations was investigated by varying the durations of the patterns before and after the events. Little evidence for event perception by integration was found; increasing the durations of the patterns either improved performance or had little or no effect on it. The final experiment examined a conflict between the present results and studies of visual integration. The ability to perceive mixtures of appearances and disappearances was investigated and found to be poorer than the ability to process either type of event alone.

The ability to detect and locate events is highly developed. This ability seems well adapted to the detection and perception of significant change in the natural environment. In contrast to the increasing scepticism concerning the function of sensory storage it is concluded that event perception is an important visual function in which sensory storage is clearly implicated.

CHAPTER 1: INTRODUCTION

1.1 Introduction and outline of aims

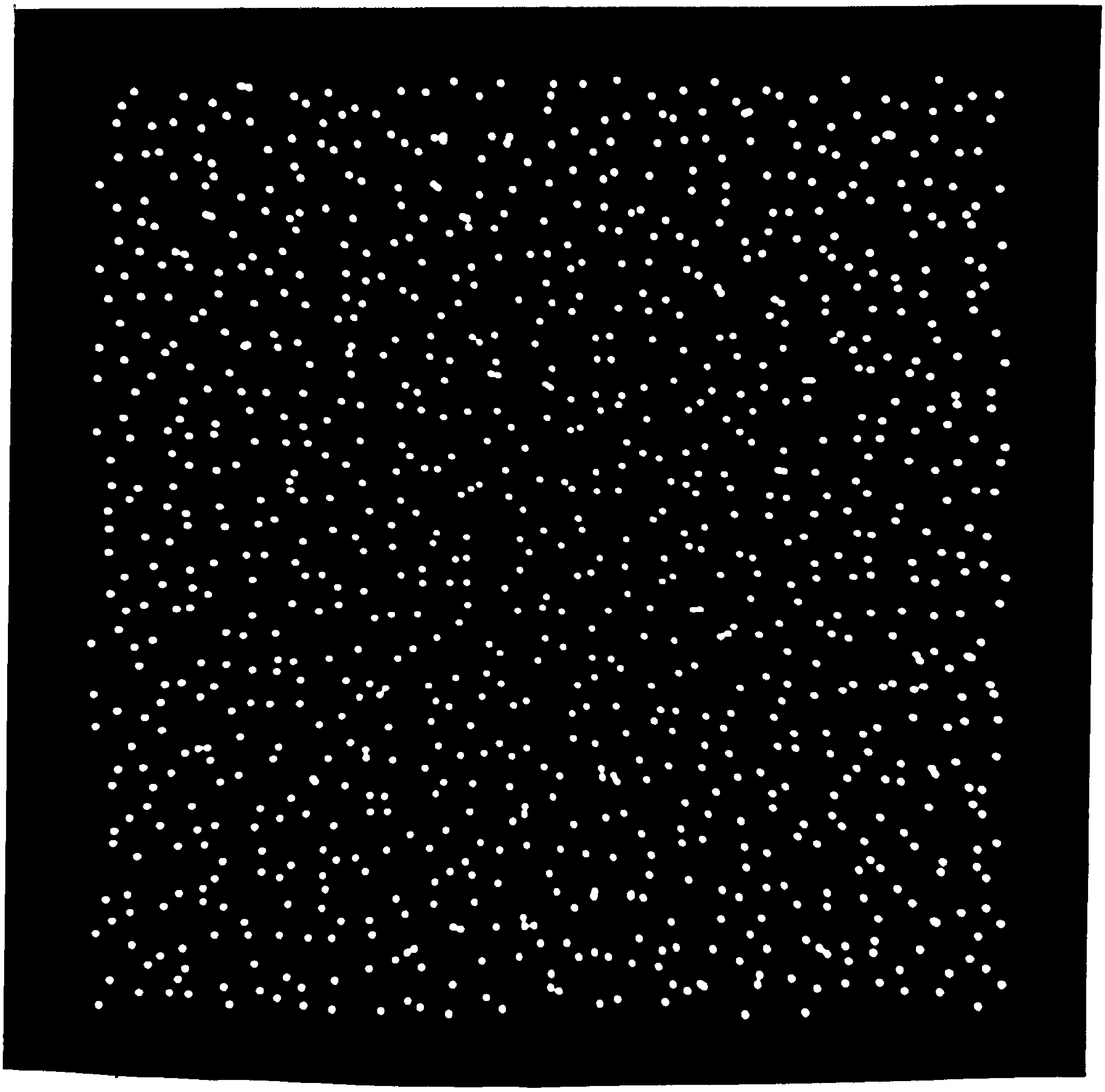
It is a common observation that changes are particularly likely to attract attention. In an environment in which survival depends on detection of prey and predator the occurrence of an abrupt change is liable to be of marked importance. Thus one would expect the capacity to relay information about events to have considerable adaptive significance. Evidence that the visual system is able to detect changes in complex stimuli comes mainly from studies of apparent motion (Anstis, 1970; Julesz, 1971; Pollack, 1972 a, b) and apparent depth (Julesz, 1971). Although many studies have involved events few have attempted to isolate them. The present experiments employed a technique which allows the ability to perceive events to be isolated and studied.

The most general definition of an event would be that it is a change in stimulus conditions over time. The present study is confined to events of a very simple kind: the appearance or disappearance of isolated dots in random dot patterns. Examples of dot patterns used as stimuli in the present study are shown in Figure 1.1. Figure 1.1(a) depicts a random dot pattern composed of 1024 dots while Figure 1.1(b) depicts the same random dot pattern with one dot subtracted. Presentation of Figure 1.1(a) followed by presentation of Figure 1.1(b) would thus constitute a disappearance while Figure 1.1(b) followed by Figure 1.1(a) would constitute an

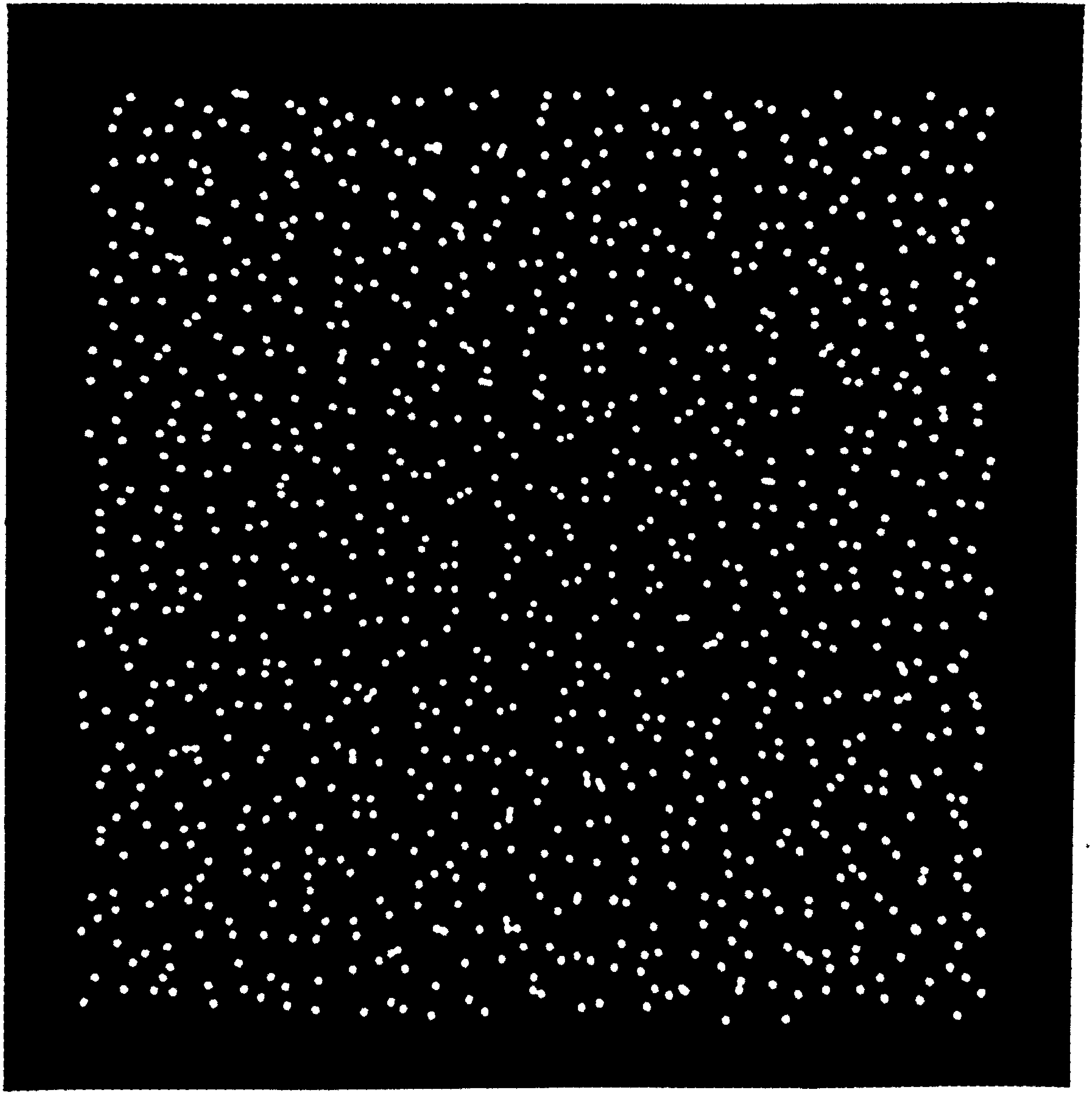
FIGURE 1.1

Examples of dot patterns used as stimuli: (a) a random dot pattern composed of 1024 dots; (b) (overleaf) the same random dot pattern with one dot subtracted.

The patterns subtended 17°57' x 17°57' when displayed. The patterns shown assume this size when viewed at a distance of approximately 40 cm.



(a)



(b)

appearance. Such events which involve an abrupt change at a particular spatial location can be distinguished from events which involve change over both time and space, as, for example, real motion or the transformation of the optic array with observer movement. Futhermore such events can be distinguished from apparent motion which involves a sequence of appearance and disappearance at different spatial locations. Although movement is probably the more typical event, appearance and disappearance are simpler and have been much less studied. The possibility that the perception of simple events underlies the perception of more complex events must be left open for the present.

Given the relative lack of data concerning the perception of simple events a first objective of any investigation must be descriptive, that is, to isolate and measure the ability and identify parameters affecting it. One aim of the following investigation was thus to explore some of the limits of the ability to detect appearances and disappearances and perceive patterns of such events. This exploration is closely connected to gaining an understanding of the function of the event perception system since the limits of the ability will depend on its function. If the event perception system serves to signal change occurring in the natural environment one would expect certain conditions to be fulfilled. Thus, for example, one would expect performance of an event detection task to be highly efficient and able to operate with complex and detailed stimulation as encountered in the natural environment. The questions posed concerning the limits of the event perception system were therefore related to hypotheses concerning its function.

Event detection and perception necessitate some form of sensory storage. This can be made clearer by considering the nature of the event detection and perception paradigms. The stimuli in the present study can be regarded as events occurring within complex patterns. However, there is an alternative way of conceptualizing such stimuli. An event is a change in stimulus conditions over time. If the stimulus before the event is denoted S_1 (e.g. Figure 1.1(a)) and after the event S_2 (e.g. Figure 1.1(b)) then the event is defined by the difference between S_1 and S_2. The difference between S_1 and S_2 will be referred to as the 'target'. In the present study the target could be either a single dot (as in Figure 1.1) or a configuration of dots. The experiments reported in Chapter 2 concern event detection: the target was a single dot and the subjects' task was to indicate whether or not an event had occurred. The logic for isolating the ability to detect events is as follows: if inspection of either S_1 or S_2 alone does not allow a target to be detected, then detecting an event will depend solely on detecting a difference between S_1 and S_2. S_1 and S_2 are presented successively thus the detection of a difference between them must, at the minimum, involve storage of S_1 and a process of comparison or combination of S_1 and S_2. Evidence that sensory storage is involved in event detection has been presented by Phillips (1974) and Phillips and Singer (1974). This evidence will be considered in detail later. The experiments reported in Chapter 3 concern event perception: the target was a configuration of dots and subjects performed a task requiring either recognition of the pattern defined by the events or discrimination of the relative visual direction of the events. In so far as event perception is possible it will require storage in addition to that required by event detection. Event perception requires detection of a difference between S_1 and S_2, however it also requires utilization of information concerning this difference. The change from S_1 to S_2 occurs virtually instantaneously, if information concerning the difference between S_1 and S_2 is to be used the outcome of their comparison/combination must be stored. Thus, for rather different reasons, both event detection and event perception require storage. It should be noted that the storage required to detect events and the storage required for utilization of event information need not be the same.

The prima facie evidence for a close relationship between sensory storage and event perception suggests that this relationship should be further explored. In particular theories and evidence from studies of sensory storage may contribute to an understanding of event perception while event perception may be particularly relevant to an understanding of both the nature and function of sensory storage. In fact it is surprising that the relationship between event perception and sensory storage has not been more thoroughly investigated previously; yet only a few studies have attempted such an investigation (Lappin and Bell, 1972; Phillips, 1974; Phillips and Singer, 1974). The reasons for the omission are complex but appear to depend on certain assumptions made concerning the nature and function of sensory storage. The sensory storage literature is vast. However, the range of explanatory concepts developed in this literature is rather restricted: it is generally assumed that sensory storage is a unitary phenomenon associated with integrative processes in the visual system. Furthermore it is usually assumed that sensory storage functions as a buffer memory system holding information to be processed by lower capacity/slower acting perceptual process. This storage is viewed as reducing the successive contrast of stimuli and suppressing discontinuity in visual input. These assumptions appear incompatible with the idea that sensory storage serves in the detection and perception of events. The following three sections attempt, therefore, to reassess some of the assumptions made concerning sensory storage. A small part of the sensory storage literature is reviewed in Section 1.2. It is argued that, although there is evidence for processes of summation and integration in the visual system, conceptions of storage solely in terms of a decaying trace or other inertial process are inadequate. Furthermore it is argued that the conflicting nature of the findings concerning sensory storage suggest that it is a plural rather than a unitary phenomenon.

Section 1.3 considers possible functions of sensory storage. It is argued that most proposals concerning the function of storage are unsatisfactory. It is proposed that one function of storage lies in the processing of visual events. Finally, Section 1.4 outlines possible explanations for the ability to detect events. Integrative processes could account for performance of an event detection task. However, this class of explanation is contrasted with that resting on processes of differentiation. Differentiation requires storage, however it implies enhancement rather than reduction of successive contrast.

Two main themes for the present study have been outlined in the preceding discussion. The relative lack of data concerning the ability to detect and perceive simple visual events argues for a search for some of the limits and characteristics of the ability. Such an investigation might hope to contribute to an understanding of the function of an event perception system. On the other hand an examination of the event detection and perception paradigms suggests, firstly, that theories and evidence from studies of sensory storage may contribute to an understanding of the principles underlying event perception and secondly, that event perception may be particularly relevant to an understanding of both the nature and function of sensory storage. To a large extent these approaches overlap: they simply pose questions at different levels of generality. In so far as there is a conflict, an attempt has been made to design experiments which ask ecologically valid questions of the event perception system, while at the same time addressing themselves to the relationship between event perception and sensory storage.

In summary, the two main aims of the following experiments were, firstly, to explore some of the limits of the ability to detect appearances and disappearances and perceive patterns of such events and, secondly, to investigate the relationship between sensory storage and the detection and perception of such events.

1.2 Studies of sensory storage

The literature relevant to sensory storage is enormous: it includes studies of flicker perception, temporal numerosity, order discrimination and masking as well as a large number of studies specifically concerned with storage. An exhaustive review of this literature will not be attempted here. Partly because reviews of these areas are to be found elsewhere and also because not all of these studies are of direct relevance here. Attention will be concentrated on six methods which have been used to study storage. Firstly, the partial report technique is discussed because it holds a particularly influential place in the literature. The radius display, probe matching tasks and subtractive reaction time studies are considered because they provide rather simple and direct measures of storage. Particular attention is paid to the Eriksen and Collins paradigm. This paradigm offers a powerful technique for investigating storage and developments of this paradigm form an important part of this thesis. Finally, consideration is given to studies using the event detection paradigm as a method for examining storage.

1.2.1 Partial report paradigm

Of the methods used to study storage most emphasis has been placed on the partial report technique developed by Sperling (1960) and Averbach and Coriell (1961). Sperling was concerned with the question of how much could be seen in a single brief exposure. When asked to report as many letters as possible from a briefly presented array of letters subjects can report only four or five letters correctly. Sperling argued that this reflects a limit on memory rather than perception and that it could be circumvented by asking subjects to report only part of the array. Sperling used a tone to signal which part of the array was to be recalled: a high tone indicated that the top row of letters was to be reported, intermediate and low tones signalled the middle and bottom rows respectively. By varying the time of onset of the tone Sperling sought to determine how much information was available both during and after stimulus presentation. Using this technique Sperling estimated that approximately nine letters were available immediately after stimulus presentation and that the asymptote of four or five letters was not reached until delays of 300msec. These findings are interpreted as evidence for a short duration high capacity store. Since Sperling's initial study there have been a large number of studies employing this technique. These studies have been reviewed elsewhere (e.g. Dick, 1974) thus the present discussion will be confined to a few remarks on the limitations of this method.

One of Sperling's most important contributions was to demonstrate that alphanumeric material could be stored. However, there are a number of disadvantages in using the partial report technique. Firstly, it is difficult to obtain an estimate of the capacity of sensory storage using this method. The superiority of partial over whole report performance is rather modest (Holding 1975); a more convincing demonstration of the high capacity of sensory storage is given by Eriksen and Collins (1967) discussed below. Secondly, alphanumeric material is highly visualizable and thus there may be a confounding between sensory storage and short-term visual memory (Phillips, 1974). It is possible that some of the longer estimates of the duration of sensory storage arise from such a confounding. Finally, the use of alphanumeric material has led to an emphasis on higher mental processes, for example reading, to the exclusion of other visual functions.

It should also be noted that Sperling did not distinguish between storage and after-images. Sperling describes an experiment which appears to demonstrate storage for periods in excess of 2 seconds (Averbach and Sperling, 1961). In this experiment the array of letters had a constant duration and intensity. When both pre- and post-exposure fields were light the duration of storage was less than 0.5 sec, on the other hand when both fields were dark performance asymptoted between 2 and 5 seconds. The longer estimate is almost certainly due to the creation of an after-image. Sperling in fact states that this presentation favours persisting after-images. The controversy surrounding the relation between sensory storage and after-images (cf Sakitt, 1975) will not be entered in detail here. However, some reasons for distinguishing after-images and sensory storage will be presented below. For the present it should be noted that this manipulation of pre- and post-exposure fields not only changes the subject's state of adaptation but also alters the nature of the stimulus. When the fields are light the stimulus is an array of dark letters, when the fields are dark the stimulus is a light field with dark letters. Thus added caution is required when interpreting Sperling's results and the results of other experiments using the same manipulation (e.g. Haber and Standing, 1970).

1.2.2 Radius display

One of the earliest measures of sensory storage was made by rotating a light and noting the speed at which it appeared to form a continuous circle. D'Arcy (1773; cited by Boynton, 1972) found that the minimum time required to produce such a circle was 133msec. Allport (1970) used a similar technique to investigate storage. Allport's display was a rotating disc with a single radial slot which was illuminated from behind by a stroboscope. This arrangement allowed for independent manipulation of flash intensity and background illumination. When viewed at flash frequencies greater than 10 Hz the phenomenal appearance was of a fan of radii rotating together as a group. Allport used an estimate of the number of radii or the angle subtended by them to measure what he terms the span of simultaneity. He obtained estimates of the duration of this span of between 30 and 200 msec. The main factors affecting the span of simultaneity were as follows: Reports of the number of radii gave a longer estimate than judgements of the angle subtended by the radii. Thus the estimate of the span of simultaneity depended on the task which the subject was required to perform. Increasing the flash intensity resulted in a decrease in the span of simultaneity. Finally, varying the surround illumination, and thus the level of adaptation, produced two categories of results: one group of subjects showed a decrease in the span of simultaneity with increasing background illumination, the other group showed no effect.

Although Allport's technique is relatively simple caution must be exercised in interpreting his results. His findings are evidence that the sensory signals generated by successive brief flashes of light overlap. They are also evidence for storage since for the signals to overlap they must extend beyond the physical offset of the flash. What is not clear however, is in what way or to what extend the signals overlap. To put this in another way, we do not know what the subjects' criterion of simultaneity was in his experiments. One possibility is that sensory signals are perceived as simultaneous if they overlap in any way. In this case the span of simultaneity would be equivalent to the perceptual duration of signals generated by brief flashes of light; since Allport's flashes were extremely brief, it would also for all practical purposes be equivalent to the duration of storage of brief flashes. However, such a simple relationship between span of simultaneity and duration of storage need not hold. The finding that estimates of span of simultaneity are task dependant suggests that the subjects' criterion of simultaneity varied with the task. It is possible that this variation was due to the differing difficulties of the tasks; alternatively the tasks may have depended to different extents on information about form and brightness.

Although the absolute duration of storage cannot confidently be inferred from Allport's results, his findings concerning the factors affecting storage are of some importance. In particular the finding that the span of simultaneity decreases as flash intensity increases argues against the idea that persistence is due to a gradual cessation of excitatory processes. Such an 'inertial' model of storage would predict that persistence would increase as stimulus intensity increased. This result also rules out an explanation in terms of after-images since it is known that the duration of after-images increases with increases in intensity (Alpern and Barr, 1962). In fact Allport was careful to distinguish after-images and persistence and instructed his subjects to ignore the former.

1.2.3 Probe matching technique

This technique was first used by Sperling (1967) and involves matching the onset of a visual or auditory probe with the offset of a stimulus. Haber and Standing (1970) used this method to estimate the persistence of an array of letters presented for between 10 and 1000msec with different combinations of pre- and post-adaptation fields. Subjects adjusted a click to coincide first with the apparent onset of the array then with its apparent offset. The interclick interval gave a measure of the perceptual duration of the array. They found that when the luminances of the adapting fields and the array were the same persistence decreased from 175msec for 10 msec presentations to 60msec for 200msec presentations and was negligible for presentation times exceeding 500 msec. When both adapting fields were dark persistence again decreased with increasing exposure duration. Under this condition, moreover, the perceptual duration of the stimulus appears to have remained constant at around 400 msec for stimulus durations of between 20 and 300 msec.

Efron (1970 a, b, c) has also used this technique to investigate the persistence of brief flashes. Efron (1970 c) used a click matching task similar to that employed by Haber and Standing. He found that persistence decreased from 120 to 0 msec as flash duration increased in the range 10 to 130 msec. Below 130 msec decreases in persistence were exactly matched by increases in duration: thus he found a constant perceptual duration of 130 msec. Beyond 130 msec there was little or no evidence for storage. Efron also found that persistence (and thus perceptual duration) decreased as flash luminance increased. Efron argues that reduction of stimulus duration below a critical duration results in a constant perceptual duration.

A rather more recent study by Bowen, Pola and Matin (1974) used a variation of this method to investigate the effect of stimulus intensity, duration and energy on storage. Bowen et al presented dark adapted subjects with two flashes at different locations: a test flash with a variable intensity and duration and a probe flash which was held constant. Subjects reported whether the offset of the test flash occurred before or after the onset of the probe flash. From these judgements the point of subjective equality of test flash offset/ probe flash onset was calculated (cf Matin and Bowen, 1976). Using this technique Bowen et al established that persistence decreased both as a function of increases in intensity and increases in duration. They also found that equal energy flashes had a constant value for persistence up to stimulus durations of 100 msec. A drawback of the particular technique used by Bowen et al is that it does not allow calculation of the onset latencies of test and probe flashes and therefore the absolute duration of storage can not be estimated. Nonetheless, Bowen et al were able to establish that their results were not simply due to differences in the onset latencies of the responses to the test flash. Thus they confirmed that there was a genuine change in perceptual duration with changes in stimulus intensity and duration and not simply a displacement of the entire response in time.

The effect of intensity on persistence found by Bowen et al agrees with Allport's results. The finding in all three probe matching studies discussed above that persistence decreases with increases in stimulus duration is further evidence against an explanation of storage in terms of inertia or after-images. The hypothesis advanced by Efron (1970 a, b, c) that there is a constant minimum perceptual duration for stimulus durations below a critical value does not receive unequivocal support from the results of the other experiments discussed. Evidence for a constant perceptual duration was found only under one of the four adapting field combinations used by Haber and Standing (1970) and for only one of the two subjects used by Bowen et al (1974). It should be noted that further evidence against the notion of a constant perceptual duration is supplied by Haber and Standing (1969). Haber and Standing (1969) asked subjects to judge whether an intermittently presented circle appeared perceptually continuous or whether it faded before the next presentation. Visual persistence, as measured by the minimum interval between presentations necessary for continuity, was found to be approximately 250 msec and independent of stimulus duration over the range 4 to 200 msec.

The finding that equal energy stimuli had equal persistence up to stimulus durations of 100 msec is evidence for summation in the visual system. The well documented reciprocity between duration and intensity is known as Bloch's law. It is important to distinguish between summation and storage. The measures of summation and storage are different. The measure of summation is the critical interval over which reciprocity holds. The figure of 100 msec obtained by Bowen et al is fairly typical for dark adapted subjects. On the other hand storage can be measured by a variety of techniques: vide the different methods discussed here. Confusion arises because summation implies a form of storage. The fact that intensity and duration are reciprocal for stimulus durations of up to 100 msec implies storage of the stimulus for 100 msec. However the storage implied by summation and the storage measured more directly need not be the same. Similarly there is no necessary connection between the duration of summation and a minimum perceptual duration.

1.2.4 Subtractive reaction time procedure

A very simple and direct method of investigating storage is that of measuring reaction time to stimulus onset and offset: subtracting reaction time to onset from reaction time to offset gives an estimate of the duration of persistence. Briggs and Kinsbourne (1972) used this technique to investigate the effect of exposure duration on storage. They presented subjects with arrays of letters or squares under monoptic or dichoptic viewing conditions. Their main finding was that persistence was inversely related to exposure duration: values of persistence ranged from 10 to 80 msec for stimulus durations of between 1000 msec and 100 msec. This result is in broad agreement with that of Bowen, Pola and Matin (1974). Briggs and Kinsbourne proposed that the relationship between stimulus duration and persistence was best fitted by a power function. Thus in their experiment a longer stimulus always had a longer perceptual duration than a shorter stimulus. Their results therefore argue against the idea of a constant perceptual duration.

Two other results obtained by Briggs and Kinsbourne are woth mentioning. Firstly, they found that the duration of persistence was the same under monoptic and dichoptic viewing conditions. If the duration of persistence is determined in the peripheral visual system, the persistence of a 100 msec dichoptic stimulus (i. e. 50 msec to each eye) should be longer than the persistence of a 100 msec monoptic stimulus. The fact that they found equal persistence under monoptic and dichoptic viewing conditions thus suggests that the persistence mechanism is central, operating after binocular confluence. Secondly, they found a trend towards greater persistence of letters than squares. When letters were presented subjects had to perform a subsidiary recall task. This result is confirmed by Erwin and Hershenson (1974). Erwin and Hershenson presented subjects with seven letter arrays and required reaction time only or reaction time plus performance of a recall task. When report of the letters was required persistence was about 35 msec longer than when the task was reaction time only. This result is reminiscent of Allport's finding that different tasks produced different estimates of storage. It is unlikely that this effect is due simply to greater central processing demands: Doost and Turvey (1971) have demonstrated that performance of a variety of subsidiary tasks does not impair performance in the partial report paradigm.

1.2.5 Visual integration

A visual integration task was used by Eriksen and Collins (1967, 1968) to investigate storage. Their stimuli were two halves of a random dot trigram. When the two stimulus halves were combined tachistoscopically the trigram could easily be recognized; either half alone, however, gave little information about the composite. Eriksen and Collins varied the interval between brief presentations of the two complementary patterns. They found that accuracy of identification of the trigram decreased as a function of ISI and reached an asymptote at between 100 and 300 msec.

Performance of the Eriksen and Collins task requires, at the minimum: storage of the first stimulus (S_1),combination of the representation of S_1 with the second stimulus (S_2), and storage of the composite to allow read out of the trigram. Thus the Eriksen and Collins paradigm is of particular interest here because the logic of their task is very similar to the logic of the event perception task. Eriksen and Collins argue that their results are evidence for a perceptual trace and a process of visual integration. The question of whether these two factors can also account for performance in an event perception task will be considered later. The present discussion will be confined to an attempt to clarify these concepts.

Implicit in Eriksen and Collins' notion of a perceptual trace is the idea that the duration of persistence is directly proportional to stimulus energy. Thus their conception of storage is a variant of the inertial model discussed previously. Their predictions, and thus this model, appear to be largely borne out by their findings. In particular they found that performance was adversely affected by a disparity in the energy of the two stimulus halves. (Eriksen and Collins, 1967; 1968). Furthermore they found that performance was generally better when the high energy half preceded the low energy half than vice versa; although it should be noted that this result was obtained under only one condition when energy was manipulated by varying stimulus duration (Eriksen and Collins, 1967) rather than stimulus luminance (Eriksen and Collins, 1968). Eriksen and Collins interpret these results as evidence that high energy stimuli generate more intense and thus by implication, longer lasting persistence than low energy stimuli. Thus Eriksen and Collins findings appear to be inconsistent with the results of the experiments discussed above suggesting that the duration of storage is indirectly proportional to stimulus energy. There are several ways of interpreting this inconsistency. It is possible that the storage evidenced in the Eriksen and Collins paradigm and the storage studied in the previous experiments are of a different form. For example, it may be that Eriksen and Collins were studying after-images or some other form of storage. However, the fact that they used low energy stimuli makes it seem unlikely that they were studying after-images. Alternatively, the results may not in fact be inconsistent. Eriksen and Collins do not present any direct evidence for variation in the duration of persistence with stimulus energy. The effect of energy may thus have been on some aspect of performance other than the duration of storage. In this context it should also be noted that the Eriksen and Collins paradigm does not give an unequivocal estimate of the duration of persistence. It is possible, for example, that stimuli are stored for a longer period than they can be integrated.

Performance of the Eriksen and Collins task implies visual integration. Eriksen and Collins use the term 'integration' to refer to at least two rather different kinds of integrative processes. Firstly, they use the term to refer to energy summation:

> ... the visual system sums or integrates energy over (a) critical duration prior to the occurrence of the perception of a form or of a brightness magnitude.
>
> Eriksen and Collins (1967) p. 476

Secondly, they also use the term to describe processes of perceptual organization:

> In the present experiments we have employed a technique of stimulation that permits the study of the temporal development of organizational or integrational components in pattern perception.
>
> Eriksen and Collins (1967) p. 477

One obvious difference between energy summation and perceptual integration is that the former is a local process while the latter is global. Thus it should be remembered that the Eriksen and Collins concept of integration encompasses at least two distinct kinds of integrative process.

1.2.6 Event detection paradigm

The event detection paradigm has been used by Phillips to investigate sensory storage (Phillips, 1974; Phillips and Singer, 1974). The stimuli used by Phillips were matrices of squares in which each square had a 0.5 probability of being filled. Subjects were presented with a matrix followed, after an ISI, by either the same matrix, or by the same matrix with one square added (appearance) or removed (disappearance). The subject's task was to indicate whether the two patterns were the same or different. This method typically yields a sensory storage time of around 100 msec (Phillips, 1974).

This paradigm is of particular interest here because it is similar to that used in the present experiments. One of the advantages of this technique is that a number of memory systems can be studied within the same paradigm. At short ISIs performance of the task involves sensory storage while at longer ISIs short- and long-term visual memories are implicated. Phillips has used this technique to compare sensory storage and short-term visual memory (Phillips, 1974) and short-term and long-term visual memory (Phillips and Baddeley, 1971; Phillips and Christie, 1977 a,b). The present discussion, however, will be confined to the studies directly concerned with sensory storage.

Phillips, (1974) investigated the effects of pattern complexity, pattern movement and masking on performance over a range of ISIs. He argues that sensory storage is evidenced at short ISIs and has the following properties: (1) High capacity, since he found highly accurate performance at short ISIs for 8 x 8 matrices. (2) Tied to spatial position, as this highly accurate performance was maintained only if the two patterns were presented in the same place. (3) Maskable, as introducing a checker board mask during the ISI removed the superior performance at short ISIs. (4) Brief, fast decay storage of about 100 msec, since the initially highly accurate performance reached asymptote at ISIs of around 100 msec. (5) Concurrent and independent processing of elements across the visual field, as size of matrix had little or no effect on reaction time.

A puzzling aspect of this study is that the evidence for sensory storage was found at long exposure durations: the first pattern was displayed for 1 sec while the second pattern was displayed until the subject responded. However, other studies have suggested that storage is negligible at long exposure durations (Haber and Standing, 1970; Efron, 1970 c; Briggs and Kinsbourne, 1972). The question arises of whether the storage being studied in these different cases is the same. Studies by Phillips and Singer (1974; Singer and Phillips, 1974) throw some light on the mechanism underlying storage in the event detection paradigm.

Phillips and Singer (1974) investigated performance in the event detection paradigm as a function of ISI, pattern 1 duration (t_1) and pattern 2 duration (t_2). They found that, at t_1=t_2 durations of 500 msec, appearances were detectable at ISIs of up to 120 msec while disappearances were detectable at ISIs of up to 60 msec. Decreasing t_1 worsened the detection of appearances but improved the detection of disappearances. On the other hand decreasing t_2 worsened the detection of disappearances. but improved the detection of appearances. In a parallel study Singer and Phillips (1974) recorded the responses of cat lateral geniculate nucleus relay cells to appearance, disappearance and interruption. The neuronal reactions to variation of ISI t_1 and t_2 correlated strikingly with the psychophysical findings. They thus proposed an explanation of the psychophysical results in terms of neuronal interactions in the visual pathway.

Phillips and Singer argue that changes are detectable because neurones respond to sudden increases or decreases in intensity with transient bursts of firing which are large relative to the subsequent maintained response. Appearances and disappearances are assumed to be detectable in so far as the transient activity they produce differs from that produced by interruptions. An appearance or disappearance involves a single change in intensity while an interruption involves two changes in intensity. The neuronal responses to two changes occurring in the same place and in quick succession interact. More particularly, LGN on - centre cells inhibit LGN off - centre cells with overlapping receptive field centres and vice versa (Singer and Creutzfeldt, 1970).
The LGN thus integrates responses: an interruption therefore differs from an appearance or disappearance because the responses to an interruption are integrated. More precisely, the on - centre cell response to an appearance differs from the on - centre cell response to an interruption because the latter is inhibited by the preceeding off - centre cell response; similarly, the off - centre cell response to a disappearance

differs from the off - centre cell response to an interruption because the latter is inhibited by the succeeding on-centre cell response. On this view the ISIs over which appearances and disappearances can be detected reflect rather different forms of storage. They claim that for the detection of appearances the ISI reflectsthe decay of inhibition of on-centre cells by off-centre cells while for disappearances the ISI depends on the duration of the transient component of the off-response.

The model proposed by Phillips and Singer explains the suppression of responses to interruptions. Their explanation is unusual in that it rests on the notion of integration of responses rather than summation of stimuli. They acknowledge that retinal mechanisms play some part in differentiating between appearance/disappearance and interruption. However, the relation between retinal andLGNmechanisms is not made clear:.. presumably at very short ISIs complete summation occurs early in the visual pathway and no responses are generated to an interruption. Phillips and Singer's concept of integration may or may not be similar to the Eriksen and Collins notion, however the same cautionary note should be added concerning the equivalence of ISI and duration of storage. It is quite possible that stimuli are stored for longer than they can be integrated.

1.2.7 Summary

The studies discussed above represent only a small fraction of the investigations of storage. Even though the discussion is selective, the picture given by these studies is confusing. The question arises of whether it is possible to develop a conception of storage in terms of a unitary store. By way of summary, the problems facing such a conception will be outlined.

Firstly, a conception of storage must make a number of preliminary distinctions. Storage must be distinguished from after-images. Similarly, the storage involved in summation must be distinguished from other forms of sensory storage. Summation has only been touched on briefly here; much relevant material is reviewed by Boynton (1972) and Ganz (1975).

A second problem facing a unitary conception of storage is the wide variation in the estimates of the duration of storage. An attempt is sometimes made to give a typical value for the duration of storage; for example 250 msec is a commonly cited figure (Haber, 1973; Dick 1974). However, in the experiments discussed above the measures range from 0 msec (Efron, 1970 c) to about 400 msec (Haber and Standing, 1970). Even if the former is an under-estimate and the latter an over-estimate there is clearly a conflict in the measures of the duration of storage which makes the assignment of a typical value inadvisable. A similar problem is encountered in attempting to assign a value to perceptual duration. The evidence reviewed above suggests that the concept of a constant perceptual duration applies only to certain studies and sometimes even then only to certain conditions.

A third problem is the number of variables affecting storage and the conflicting evidence as to how storage is affected by these variables.

There is contradictory evidence concerning the effect of the physical properties of the stimulus on the duration of storage. A number of studies indicate that persistence decreases with increasing stimulus duration (Bowen et al, 1974; Briggs and Kinsbourne, 1972; Efron, 1970 a, b, c; Haber and Standing, 1970); on the other hand, other studies imply that the duration of storage is independent of exposure duration (Sperling, 1960; Haber and Standing, 1969). Again, there is evidence that storage is negligible at long exposure durations (Briggs and Kinsbourne, 1972; Efron, 1970 c; Haber and Standing, 1970) while other studies (Phillips, 1974; Phillips and Singer, 1974) have suggested that it is not. Similarly there is evidence that storage decreases with increasing stimulus luminance (Allport, 1970; Bowen et al, 1974; Efron, 1970 c); however, there is also the suggestion that storage may increase with increasing luminance (Eriksen and Collins, 1968). There does appear to be a consensus that storage is longer under dark adapted than light adapted conditions (Sperling, 1960; Haber and Standing, 1970; Allport, 1970); even so, the manner in which level of adaptation has been manipulated can often be criticized. It may be that these inconsistencies are apparent rather than real. It was suggested above, for example, that Eriksen and Collins' results were not necessarily due to an effect of luminance on the duration of storage. However, the findings concerning the effect of exposure duration remain particularly puzzling.

Further complexities are added by the observation that the duration of storage is not only stimulus dependent but also task dependent. There are gross differences in the estimates of storage obtained in different paradigms. However, differences are also found when storage of the same stimulus is estimated by slightly differing methods (Allport, 1970) or when storage is measured by the same method with or without a subsidiary task (Erwin and Hershenson, 1974).

The conflicting evidence concerning the nature of storage militates against a conception of storage in terms of a unitary store. Moreover it suggests that a number of different forms of storage may have to be distinguished. Storage, therefore, may well be a plural rather than a unitary phenomenon.

1.3 Functions of sensory storage

Arguments and evidence concerning possible functions of sensory storage are surprisingly rare in the literature. Any discussion of function thus requires a certain amount of reading between the lines. The fact that function tends to be implicit rather than stated may in part be due to a belief that the nature and function of storage are not to be distinguished. It is commonly remarked that experimentation tends to be phenomena driven (Newell, 1975; Allport, 1975): phenomena tend to be treated as significant per se. A consequence of this approach appears to be the view that an adequate account of the function of storage is given simply by demonstrating that storage is evidenced under certain conditions. However, from the fact that storage is apparent under certain conditions it does not follow that it has any value for visual functioning under these conditions. Thus although function requires evidence, evidence does not imply function.

An uncontroversial statement of the function of storage is that it serves to maintain information. This is the case simply by definition. However, this truism has an important consequence. Clearly it is unnecessary to maintain information which is freely available. Therefore, essential to an account of the function of sensory storage is a specification of the conditions under which visual input is not continuous. In the following review different possible functions will generally be classified according to the kinds of discontinuity to which they relate.

The discussion of the nature of sensory storage emphasized the distinction between storage and energy summation. The function of summation is a matter of less controversy than the function of storage, thus it will be considered first. The discussion left open the possibility that other distinctions might be made. Thus in considering the possible functions of storage it should be borne in mind that storage may not have a single function.

1.3.1 Energy summation

No physical system can be infinitely responsive to temporal change. Thus there is a necessary limitation on the temporal responsiveness of the visual system. The period of summation sets the limit on the discrimination of successive stimuli occurring in the same position. Thus summation can be regarded as a necessary limitation of the visual system, a view of storage originated by Helmholtz (1867). However, although this view is essentially correct, it is misleading in so far as it suggests that summation is a defect.

Summation can be conceptualized as a compromise between conflicting demands placed on the visual system (Levick and Zacks, 1970). In electrical and mechanical devices there is a well known trade-off between sensitivity and acuity/rapidity of response. Although summation in the visual system involves a loss of temporal acuity it results in an increase in sensitivity. Summation thus aids the detection of low intensity stimuli. Furthermore it seems probable that summation also increases spatial acuity. Integration over time allows position to be calculated on the basis of average rather than instantaneous retinal location. (Riggs and Ratliff, 1951). Thus summation represents a compromise between temporal acuity and the demands of sensitivity and spatial acuity. Such a compromise is not only necessary but also desirable. There are a number of sources of noise in the visual system: variation in the quantal absorption rate, minor perturbations in the eye, etc. A response to such minor changes in input would be undesirable. Thus summation controls the threshold for the response to fluctuations.

Summation thus has a very specific role in relation to discontinuities in input to the visual system. This role is quite distinct from the proposed functions of storage to which the succeeding discussion is confined.

1.3.2 Storage functions to buffer over saccadic eye movements

An obvious discontinuity in visual input is that caused by saccadic eye movements. Lindsay and Norman (1972) suggests that storage is useful in, among other things, "....maintaining a continuity of perception during the time it takes to complete an eye movement". However, this statement of the function of storage leaves a number of questions unanswered: for example, what is meant by 'continuity' here? How long does the representation remain stored? It is helpful to enumerate and consider three ways in which storage may relate to eye movements:

(a) A sensory representation may be stored over a saccade and into the next fixation.

(b) A representation may be stored over a saccade but not into the next fixation.

(c) A representation may not be stored during a saccade at all.

(a) Evidence that storage can extend over eye movements and into a subsequent fixation is cited by Dick (1974). This is the case not only for brief stimuli (Davidson, Fox and Dick, 1973) but apparently also for long stimuli (Doerflein and Dick, 1974; cited in Dick, 1974). The idea that a previously stored representation remains after an eye movement finds support from the results of an experiment by Hall (1974) Hall observed eye movements while subjects performed a partial report task similar to Sperling's. He found that subjects had a strong tendency to look where the requested stimulus had been. Hall argues that his results imply spatial scanning of an iconic image.

The suggestion thus appears to be that information from successive fixation can be integrated into a composite sensory representation. There are, however, a number of problems with this view of the function of sensory storage. Firstly, although there is evidence for storage into the next fixation there is no evidence that a sensory representation remains for multiple fixations. Thus only a very limited sensory representation could be elaborated. Secondly, sensory representation is in a rich and topographically specified form (Phillips, 1974). Neisser (1968), however, has pointed out that feedback about eye movements is too inaccurate to allow such a representation to be constructed from successive fixations. Furthermore such a composite representation would have to be in ordinal rather than anatomical co-ordinates: storage of a representation in anatomical co-ordinates would simply result in superposition of images from successive fixations. However, it is unclear whether sensory representation is in ordinal co-ordinates. The results of the Davidson et al experiment imply an anatomical representation while an experiment by White (1976) suggests an ordinal representation. White argues that the inconsistency between these findings is due to a difference in the type of eye movements studied in the experiments: his own experiment involved smooth pursuit eye movements while the Davidson et al experiment involved saccadic eye movements. Thus the evidence suggests that, for the type of eye movements of interest here, storage is in anatomical rather than ordinal co-ordinates. Finally one might question the value of devoting space to the storage of a literal representation when the actual stimulus array is readily available. One can normally fixate or refixate any desired portion of this array. Detailed stimulus information is thus effectively 'stored' in the stimulus array itself.

(b) It might be argued that the findings cited above indicate that a representation is stored over an eye movement but are untypical in that storage is usually terminated by or before the next fixation. This view is proposed by Sperling (1969):

> The function of the persistence (the storage aspect of VIS (Visual information storage)) seems to be to maintain a visual image from one fixation of the eye to the next: the function of erasure is to permit the new image following a saccad to overwrite the trace of the previous one without interference to itself .....
>
> Sperling (1969) p. 21

Storage over eye movements would allow information from a fixation to be processed during the interval before the next fixation. Such an arrangement would increase the efficiency of visual processing since it would allow it to be continuous. This view of the function of storage avoids the objections made to the previous view; however, it raises problems of its own. Firstly, it would not in fact increase the time for which the stimulus was available very greatly. Saccadic eye movements occupy only about 10% of viewing time (Noton and Stark, 1971), thus this figure is the upper limit on any saving which could be achieved. Secondly, it has been objected by Neisser (1977) that the contents of such a buffer would be masked by input during eye movements. It is possible that masking is minimized by saccadic suppression of neural origin (Riggs, Merton and Morton, 1974). However, even if this is the case, proponents of this view would still have to demonstrate that suppression operated only on the input and not on the buffer.

(c) The third possibility outlined above was that a representation is stored during fixation only. If this is generally the case then both of the above views of the function of storage would be discounted. There is certainly evidence for periods of storage much shorter than the average duration of fixation (Efron, 1970 c; Briggs and Kinsbourne, 1972). In fact part of the rationale for tachistoscopic presentation is that it controls for eye movements; thus the majority of findings concern storage during fixation. Therefore, even if storage does have a function in relation to saccadic eye movements, it nonetheless seems reasonable to suppose that it also has a function during fixation.

1.3.3 The orthodox view of the function of storage

In the literature one finds a conception of the function of storage which is pervasive enough to warrant the title of the orthodox view. On this conception storage functions to maintain sensory information until it can be processed by higher level mechanisms. It is a view which can be traced to Hebb's suggestion that memory consists of a brief neural activity phase and a second permanent structural phase (Hebb, 1949). In Hebb's view the function of the activity phase was to maintain the information until a structural cell assembly could be established. Information processing concepts replace Hebb's neurophysiological constructs in the following statement from Averbach and Sperling (1961).

> The visual process involves a buffer storage of relatively high capacity that can take in information virtually instantaneously and retain it to permit its relatively slow utilization.
>
> Averbach and Sperling (1961) p. 210

The same view is to be found between the lines in Neisser (1967): a more recent statement of the orthodox view comes from Turvey (1973):

> Iconic storage is seen as a buffer memory system in which the input can be held in a literal form for several hundred milliseconds during the course of conversion to response and/or short-term categorical storage.
>
> Turvey (1973) p. 2

Presentations of the orthodox view often gain an initial plausibility by blurring the distinction between sensory storage and sensory representation. For example, Massaro (1975) uses the terms 'image' and 'storage' interchangeably. Without prior clarification of the terms such usage is highly misleading: it seems to imply that the concepts are equivalent. Clearly there is a distinction between sensory storage and sensory representation. The distinction is important because, although 'storage' implies 'representation' (i. e. 'something being stored'), 'representation' does not imply 'storage'. Thus it is quite possible to conceptualize a representation or image which is not stored. Such would be the case, for example, if input were continuous during fixation: here one would simply have a continuously available representation.

A common argument for the orthodox view is that a buffer is required because there is a change in rate and capacity of processing in the visual system. The concept of a change in rate and capacity arises directly from Sperling's work with the partial report paradigm (Sperling, 1960). Sensory information must be retained, it is argued, while slower acting/lower capacity central processing is accomplished. However, it is a non-sequitur to argue from a change in processing power to the need for a buffer. A change in rate/capacity is simply not sufficient to require a buffer. A buffer would only be desirable if the information was not otherwise maintained. If visual input is continuous during fixation a buffer is redundant. Perhaps part of the credence which if given to this argument arises from an implicit analogy with machine based information processing systems. It is common programming practice to use a buffer where there is a change in processing power as, for example, between an input device and the CPU. Such buffering, however, is only desirable in the context of a number of other considerations, the most important of which is that machine information transmission is serial and intermittent. Thus buffering is only desirable in machine information processing because information is not continuously available.

The conclusion of both of the above arguments is that storage is unnecessary if visual input during fixation is continuous. A further argument bearing on this point derives from Neisser. (1976). Neisser states rather baldly that, "by definition iconic memory does not exist during fixation". Presumably what Neisser means is that a stimulus which is being fixated cannot logically be stored. This point can be restated in the following way: if a representation is dependent on the continuing physical presence of the stimulus one cannot say that it is stored. This does not, as Neisser appears to believe, constitute a refutation of the orthodox view. It does, however, put the onus on the proponents of this view to show that the iconic representation is independent of the stimulus during at least part of the period of fixation. Thus discontinuity in visual input during fixation is logically required by the orthodox view; in fact, more sophisticated presentations of the view fulfil this requirement (Dick, 1974; Coltheart, 1977). The succeeding discussion will be confined to a consideration of the arguments and evidence for this view.

The most convincing argument for the orthodox view is based on studies of the effect of exposure duration on persistence. The effect of exposure duration has been alluded to earlier; the investigations by Sperling (1960) and Haber and Standing (1970) are of particular interest here. Sperling obtained evidence that the perceptual effect of a stimulus was independent of exposure durations from 15 to 500 msec. Similarly Haber and Standing's results suggest that, for stimuli of less than 250 msec perceptual duration is largely independent of exposure duration. If perceptual duration is independent of stimulus duration it can be argued that the energy contained in longer exposures is redundant. For example if both a 50msec stimulus and a 250msec stimulus have a perceptual duration of 300msec then the presence of the longer stimulus for 200 msec more than the shorter is perceptually irrelevant. Thus these results can be regarded as prima facie evidence for the conclusion that the iconic representation is independent of the physical presence of the stimulus during part of the period of fixation.

Consideration of the above studies gives rise to a particular conception of the form of early visual processing. (Dick, 1974; Coltheart, 1977). It is that the process of sensory registration (i.e. read-in to iconic memory) takes place over some brief period, possibly at the beginning of fixation, and beyond that information is held in storage independently of the stimulus array. Visual input is thus conceptualized as a discontinuous process. The icon is regarded as beginning at, or shortly after, stimulus initiation and continuing whether the stimulus is present or not.

There are, however, a number of criticisms of this view of early visual processing. The argument cited in favour of this view is not logically compelling. It is quite consistent to accept that stimuli of different durations have equal perceptual durations while denying that the representation is independent of the physical presence of the stimulus. For example the evidence is equally consistent with the notion that storage makes short stimuli appear longer but is unnecessary if the stimulus is of long duration. Thus the plausibility of this view depends on it providing a particularly simple and coherent interpretation of the evidence. The problems facing such an account have been outlined in the previous section. The model can accommodate summation simply by assigning it the role of sensory registration (Coltheart, 1977). However, it is not clear that it can overcome the other difficulties discussed above.

The Dick - Coltheart model rests rather heavily on the notion of a constant perceptual duration. This idea has already been criticized: it applies only to certain studies and even then only under certain conditions. Furthermore, to be plausible the model requires that perceptual duration exceeds a particular value. It is sometimes argued in favour of this view that there is a correlation between the duration of storage and the duration of fixation (Dick, 1974). The model would certainly be more convincing if perceptual duration generally equalled or exceeded 250 msec: an eye movement could then have the role of initiating a new iconic representation (Coltheart, 1977). However, studies indicating a constant perceptual duration have often suggested a rather shorter period. For example, Efron (1970 c) found a constant perceptual duration of 130 msec. The model thus might require the introduction of mechanism of periodic refreshment other than eye movements. There is a well established precedent for such a hypothesis (Stroud, 1956); however, the model would lose much of its initial simplicity with such an addition. A further problem for this model is the finding that estimates of storage are task dependent: the model offers no obvious explanation of this result.

A final argument against this conception of storage concerns the loss of real time processing it implies. If information is only registered for some brief interval (or intervals) during fixation then information about changes in the array occurring outwith this interval will either be delayed or lost entirely.

In defence of this conception of sensory storage it might be argued that it only seeks to explain certain findings. It was noted above that there may be a number of different forms of sensory storage. Thus the orthodox view may offer a correct description of one form of storage: that which is consistent with the Dick-Coltheart hypothesis. Although this may be the case, the model would clearly lose much of its original force with such a qualification.

1.3.4 Storage buffers over interruptions

The visual field is often temporarily not visible. Interruptions may be due, for example, to blinks or to an object moving across the line of sight. Phillips and Singer (1974) suggest that storage allows changes which occur during interruptions to be detected. This view of the function of storage is supported by their experimental findings discussed above. It will be remembered that they found that appearances in complex stimuli were detectable with ISIs of up to 120 msec while disappearances were detectable with ISIs of up to 60 msec. Thus their results indicate that changes which occur during interruptions of up to 120 msec can be detected.

Much of the credibility of this account rests on the duration of interruption over which events can be detected being fairly long. A partial replication of the Phillips and Singer experiment is to be found below: in this case the results suggest that events are detectable with ISIs of only up to 32 msec. A similar result is reported by Lappin and Bell (1972). If this shorter period is more typical then the generality of this account is much reduced.

1.3.5 Storage buffers over eye tremors

The possibility that storage functions to buffer over saccadic eye movements has already been considered. The eye movements which occur during fixation are of two kinds: a slow drift on which is superimposed a fast irregular tremor. One would expect eye tremors to decrease visual acuity, however this does not appear to be the case: acuity is considerably better than would be expected from a consideration of the physiological imperfections of the eye. Dodwell (1971) has suggested that perceptual clarity is achieved by a process of auto-correlation. He proposes that successive time samples of retinal input are correlated to yield a similarity function. Clarity can only be achieved if different images are correlated: nystagmus thus plays the role of providing different images while storage functions to maintain them.

As it is stated here, this view of the function of storage appears to be a particular version of the more general proposal that integration over time increases spatial acuity. As such it might be treated as a hypothesis about the function of summation rather than storage. Dodwell, however, suggests that the notion of auto-correlation embraces a much wider range of phenomena including stabilized image fading/regeneration and Haber's repetition clarity effect. (Haber, 1969). It is not clear, however, that phenomena with such disparate time courses can be attributed to the same mechanism. Tremors, for example, occur at a rate of around 90/sec (Riggs and Ratliff, 1951) while the repetition clarity effect spans periods of 900 msec (Haber, 1969) and image fading takes place over even longer periods (Yarbus, 1967).

1.3.6 Storage is required when the visual field is briefly illuminated

The visual field is sometimes only visible briefly. This occurs, for example, during lightning storms and under certain conditions when driving at night. Storage allows processing of visual scenes which are only briefly illuminated. Haber has suggested that, if nothing else, storage would at least allow one "to read in the dark during a lightning sotrm" (Haber, 1970 p. 110). However, the tongue in cheek nature of Haber's suggestion makes it clear that as a function of storage this is extremely ad hoc and unlikely. Storage may allow such stimuli to be processed. However, the proposal that storage only functions under these conditions is equivalent to suggesting that storage does not have a function in normal viewing.

1.3.7 Storage does not have a function

The view that storage has no function is being increasingly advanced (Barber and Legge, 1976; Neisser, 1976; Turvey, 1977). Turvey, for example, argues that storage is a defect analogous to chromatic aberration. However, the view does not require that storage is a defect, it may simply be irrelevant to normal visual processing.

The argument advanced for this position is that storage is only evidenced under unrepresentative viewing conditions. Most studies of storage have employed tachistoscopic presentation of stimuli.

Tachistoscopic viewing is unlike normal viewing in that stimuli are only illuminated briefly thus depriving the subject of eye movements. It is thus possible that storage is an artefact of tachistoscopic presentation and that it does not have a function under normal perceptual circumstances.

As with any sceptical position, the view that storage has no function is essentially irrefutable. Nonetheless, storage is a pervasive phenomenon. It is evident under conditions other than brief tachistoscopic presentation of stimuli (Phillips, 1974; Phillips and Singer, 1974).

1.3.8 Storage functions in the processing of events

The most general definition of an event, as noted earlier, would be that it is a change in stimulus conditions over time. The term 'visual event' can thus encompass a broad class of visual phenomena including not only appearances and disappearances but also brief stimuli and moving stimuli. The characteristic which these phenomena have in common is that they involve a more or less rapid change in the visual stimulus. Thus events fulfil the logical requirement for storage. of producing discontinuity in visual input. There are a number of reasons for believing that the function of storage lies in the processing of such events.

This view of the function of storage is consistent with the evidence for storage. The evidence for storage comes mainly from brief presentations of stimuli. Brief stimuli represent one kind of visual event. This position stands in partial agreement with the sceptical argument discussed above. The tachistoscopic presentation of a stimulus is unlike normal viewing in that it involves brief illumination of the entire visual field. The position adopted here departs from the sceptical view in regarding tachistoscopic presentation as representative of visual events. Brief illumination of the visual field is unusual, however, brief stimuli within the visual field are not. The significance of tachistoscopic evidence for storage can therefore be found in its implications for the processing of events.

Unlike the orthodox view the position argued for here does not require a unitary conception of storage. A number of different kinds of event can be distinguished thus one would expect there to be a number of aspects to event processing. Thus, for example, the storage evidenced with brief presentations of stimuli may not be the same as that involved in the detection of appearances and disappearances.

It was noted earlier that one of the commonest arguments for the orthodox view is that information must be maintained while slow acting/ low capacity central processing is accomplished. It was argued that a change in rate/capacity was not a sufficient condition for buffering normally fixated stimuli. However, it is a sufficient condition for buffering events. Events involve a rapid change in stimulus conditions. Thus if information concerning events is to be processed by central mechanisms it must be maintained. This is the case both for brief stimuli and, in so far as information concerning them can be used, for appearances and disappearances. Again, however, the storage which extends brief stimuli need not be the same as that involved in maintaining information concerning appearances and disappearances.

In conclusion, the view that storage functions in processing of visual events is both logically coherent and consistent with the available evidence. The present study is concerned with a particular kind of visual event: appearances and disappearances in complex stimuli. It is hoped to show that one function of storage lies in the detection and perception of such events.

1.4 Event detection

Many studies have involved appearances and disappearances, however, few studies have attempted to isolate them. The following section considers what is known concerning the ability to detect appearances and disappearances in complex stimuli and attempts to develop two possible explanations for performance of an event detection task.

It was noted earlier that performance of an event detection task can be conceptualized as requiring detection of a difference between the first (S_1) and second (S_2) patterns. The ability to detect a difference between successive stimuli must, at the minimum, involve storage of S_1 and the capacity to compare or combine S_1 and S_2. The evidence presented by Phillips (1974) that sensory storage is involved in event detection has already been considered. Briefly, Phillips found highly accurate performance at short ISIs in the event detection paradigm. He reported evidence that the storage underlying this performance is high capacity, short duration, tied to spatial position, sensitive to masking and allows concurrent and independent processing of elements across the visual field.

The physiological model proposed by Phillips and Singer (1974; Singer and Phillips, 1974) also suggests that sensory storage is involved in the detection of appearances and disappearances in complex patterns. Moreover, their model implies that the processes on which the detection of events depends occur at and prior to the lateral geniculate nucleus. Phillips and Singer presented further evidence that performance of an event detection task was dependent on peripheral processes. They compared performance under monoptic and dichoptic viewing conditions. S_1 was a 10 x 10 matrix in which each cell had a 0.5 probability of being filled; S_2 was either the same pattern, or the same pattern with one cell added or removed. The subjects' task was to indicate whether the two patterns were the same or different. When both S_1 and S_2 were presented to the same eye performance was nearly perfect; however, when S_1 and S_2 were presented to different eyes under conditions of binocular fusion performance was close to chance. Thus, with complex patterns, central processes are unable to detect changes on the basis of a comparison between separate representations of S_1 and S_2. This result is in apparent conflict with the finding that differences between successively presented binocularly fused stimuli can be utilized for the perception of depth and movement (Beverley and Regan, 1974; Julesz, 1971). All that this result implies, however, is that event perception and depth and movement perception reflect rather different visual processes. In particular it suggests that depth and movement can be computed by central processes while the representation which enables events to be detected is dependent on peripheral processes.

The detection of a difference between S_1 and S_2 requires a comparison or combination of the stimuli. The evidence reviewed above suggests that the comparison or combination of S_1 and S_2 is dependent on sensory

processes. Evidence for two broad classes of successive interaction is to be found in the sensory storage literature. Following Kahneman (1968) these can be termed 'integration' and 'interruption'. Evidence for integrative procces in vision was considered above in the review of studies of sensory storage. The evidence for interruption of one stimulus by another comes mainly from studies of visual masking (Kahneman, 1968; Turvey, 1973). Processes of integration and interruption are not mutually exclusive: Turvey (1973) has presented evidence that both play a part in visual masking. The question arises of whether either of these kinds of successive interaction can account for performance of an event detection task. The notion of interruption clearly can not: if S_2 simply replaced S_1 no difference between them could be computed. On the other hand integration implies that successive stimuli overlap: thus integrative processes could account for performance of an event detection task.
The possibility that event detection can be explained in terms of integrative processes will be considered in more detail below. Neither integration nor interruption suggest that changes are enhanced; integrative processes, in fact, imply a reduction in successive contrast. However, the idea that changes are enhanced by the visual system is common in the physiological literature. The term 'differentiation' will be used in the succeeding discussion to refer to processes which imply enhancement of successive contrast.

(a) Integration: The term 'integration' is being used here in a very broad sense to refer to visual processes which imply a reduction in successive contrast. Integrative processes could account for event detection in the following way: When a change in the stimulus occurs the effect of integrative processes is to produce a gradual change from sustained to background levels of response or vice versa. An area of change will therefore be identifiable because it is in transition from sustained to background levels of response over a certain period. No other temporal comparisons are necessary. because areas which are at intermediate levels of response can be identified by comparison and sustained levels of response. Level of response need not be reflected in apparent brightness, however, one way in which an area of change may be identifiable is by the fact that it has an intermediate apparent brightness.

Integration is used here to refer to a class of processes which might explain event detection rather than a single process. However, it is helpful to consider two specific examples of integrative processes. The first example is a conception of persistence from Haber and Hershenson (1974). Haber and Hershenson regard persistence as a process of gradual decay in the representation of a stimulus. They describe persistence as an apparent fading from view in, among other places, summarizing their review of visual persistence studies:

> ... we discussed the apparent duration of a brief visual stimulus as a measure of how long a brief pulse appeared to persist before it faded out.
>
> Haber and Hershenson (1974) p. 167-168.

A schematic representation of the visual response to a brief stimulus hypothesized by Haber and Hershenson is shown in Figure 1.2 (a). If Haber and Hershenson's conception of persistence is correct, disappearances in complex stimuli may be detectable because they appear faded in comparison to surrounding steady state elements. It is not clear,

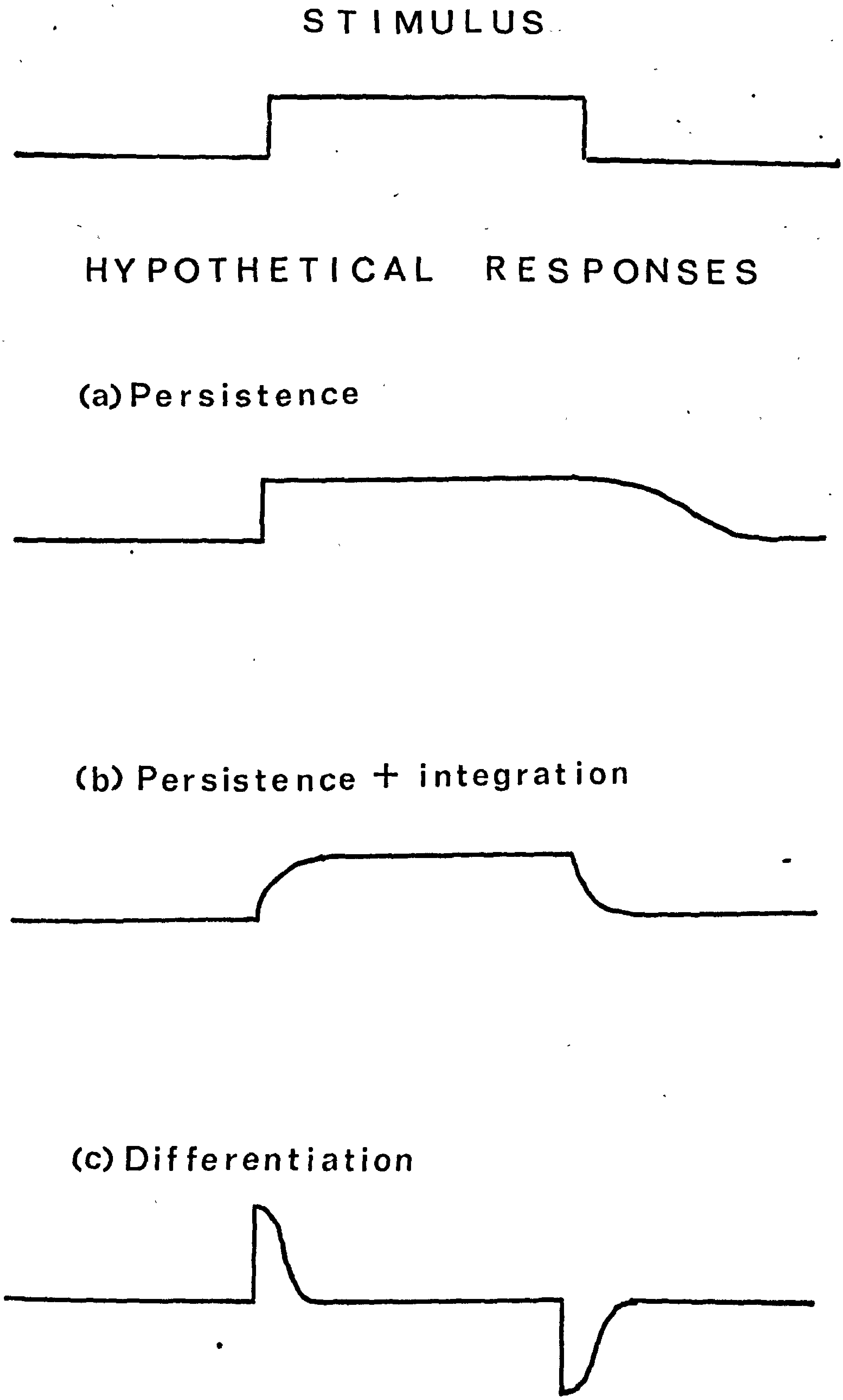
FIGURE 1.2

Schematic representation of a variety of hypothetical visual responses to a stimulus.

(a) Persistence. Example from Haber and Hershenson (1974) p. 137.

(b) Persistence and integration. Example based on Penner (1975) p. 118.

(c) Differentiation.



STIMULUS

HYPOTHETICAL RESPONSES

(a) Persistence

(b) Persistence + integration

(c) Differentiation

Fig 1.2 opposite legend on p 52

however, that appearances would be detectable in the same way.

The second example is from Penner (1975). Penner has presented a mathematical model of sensory processing incorporating both persistence and a process of continuous integration. Penner's model is designed to fit data from studies of audition, however, he implies that the model is generalizable to other sensory modalities, particularly vision. The idea of a model incorporating both persistence and integration is of particular interest here because it is precisely such a model which is argued for by Eriksen and Collins (1967; 1968). The hypothetical output of a process of persistence plus integration to a stimulus is shown schematically in Figure 1.2 (b). As can be seen the output of such a process is in a state of transition from background to sustained levels and vice versa for a certain period after both stimulus onset and offset. Thus such a model could explain the detection of both appearances and disappearances in complex stimuli.

(b) Differentiation The term 'differentiation' will be used to refer to processes which imply an enhancement of successive contrast. A theory of event detection incorporating processes of differentiation thus emphasizes the capacity of the visual system to react directly to changes. The essence of this model is that elements common to S_1 and S_2 are suppressed while differences are enhanced. It is the functional rather than the mathematical aspects of the concept of differentiation which are of interest here. However, for the purpose of illustration the hypothetical output of a process of differentiation is shown schematically in Figure 1.2 (c).

In constructing Figure 1.2 (c) it was assumed that differentiation was preceded by a process of integration such as that postulated by Penner (1975)

That there are differential processes in vision is well established. As one elementary textbook notes:

> The basic rule of the nervous system seems to be to find changes in the signal pattern. Differences are noted; constancies tend to be suppressed.
>
> Lindsay and Norman (1972) p. 111

The presence of processes which enhance spatial contrast has been substantiated both psychophysically and neurophysiologically (Ratliff, 1965; Cornsweet, 1970). Temporal differentiation has been postulated to explain dark adaptation (Cornsweet, 1970) and the fading of stabilized images (Arend, 1973). More importantly, there is physiological evidence for processes which enhance successive contrast in a manner analogous to the enhancement of spatial contrast. A relatively small increase or decrease in stimulus intensity produces a large, transient response from neurones in the visual pathway (Adrian and Mathews, 1927; Hartline, 1938; Ratliff, Hartline and Miller, 1963). It is generally assumed that such transients serve to enhance changes. Evidence for a correlation between transients and the detection of appearances and disappearances in complex patterns has already been considered: Phillips and Singer's physiological model of event detection is based on the proposal that such transient responses serve to make events detectable.

It is not being suggested that the concept of differentiation could replace that of integration. The review of studies of sensory storage indicated that there was evidence for a variety of integrative processes in the visual system. Thus if there are processes of differentiation they must be additional to processes of integration. This can be made clearer by considering the relationship between these psychophysical constructs and the physiological model proposed by Phillips and Singer. As mentioned previously, Phillips and Singer argue that changes are detectable because neurones in the visual pathway respond to such changes with transient bursts of firing. Transient responses can be regarded as differential in that, firstly, they occur only when a sudden change in stimulus conditions takes place and, secondly, they are large relative to the response to sustained stimuli. Transient responses, however, also appear to reflect energy summation: the magnitude of the transient response shows time-intensity reciprocity (Levick and Zacks, 1970). Furthermore, the model proposed by Phillips and Singer implies that transient responses interact with each other locally in a way which can be regarded as integrative. Thus integration and differentiation are not mutually exclusive.

Some evidence against an integration theory of event detection has been presented by Lappin and Bell (1972). Lappin and Bell investigated the ability to detect and identify differences between successive stimuli. Their stimuli were composed of a fine grained, randomly textured shading material; the target stimuli were semicircular forms composed of an area of the same material. The ability to identify the position and orientation of the target stimuli was investigated as a function of the luminance and contours of an intervening stimulus and as a function of ISI. The durations of first and second patterns were the same and equal to 300 msec. At an ISI of 0 msec the position and orientation of the target could be identified quite accurately. Performance declined as ISI increased, falling to chance at ISIs of 30 msec under all conditions except that in which the intervening stimulus was a dark field. They also found that performance with an ISI of 0 msec was superior to performance with simultaneous presentation of the patterns. This demonstration of identification of forms defined solely by a difference between successive stimuli is similar to that described by Julesz (1971). Lappin and Bell present three arguments against an explanation of performance in their paradigm in terms of integration. Firstly, they argue that perception of a difference requires correlated patterns in contrast to the uncorrelated patterns that produce masking when integrated. However, although this serves to distinguish event detection and integration paradigms it does not rule out the possibility that the same process is responsible for the effects obtained in these paradigms. Secondly, they argue that the ability to identify differences operates over a shorter range of ISI than does integration. This claim, however, appears to rest on certain assumptions made concerning the time course of integration which are not clearly substantiated by Lappin and Bell. Moreover, Phillips and Singer (1974) have demonstrated that, under appropriate conditions, near maximal performance can be obtained in the event detection paradigm with ISIs as long as 100 msec. Finally, Lappin and Bell argue that the superiority of performance with successive presentation over performance with simultaneous presentation militates against an explanation in terms of integration. This argument appears reasonable. If it is assumed that an overlap or superposition of S_1 and S_2 would be the basis for event detection via integrative processes then on an integration theory physical superposition should yield performance which is at least as good as successive presentation. The fact that this is not the case suggests that integrative processes are not responsible for event detection. Although Lappin and Bell refer to their task as that of 'perceptual differentiation' they favour an explanation of event detection in terms of correlational processes similar to the binocular fusional processes posited by Julesz (1971). However, as already noted, an explanation in terms of central processes appears to be ruled out by the effects of dichoptic presentation on event detection reported by Phillips and Singer (1974).

Integration and differentiation theories yield specific predictions concerning the ability to detect appearances and disappearances in complex stimuli. Three of the following experiments are directly concerned with testing such predictions. In so far as differentiation theory implies that the visual system is particularly designed to detect changes it predicts that the level of performance in an event detection task will be relatively high. Furthermore, differentiation theory implies that the visual system enhances change and suppresses steady state stimuli. Thus manipulation of the steady state properties of the stimulus array should, on this theory, have relatively little effect on performance of an event detection task. Integration theory does not make a specific prediction concerning the level of performance to be expected in an event detection task. However, in so far as integration theory implies that events can be detected because they appear faded in comparison with surrounding elements it predicts that inhomogeneity in the luminance of surrounding elements will adversely affect performance of an event detection task. The above predictions are tested in Experiments I and II. Experiment VI is concerned with predictions arising from the integration theory proposed by Eriksen and Collins (1967; 1968). Eriksen and Collins argue that integration is adversely affected by inequalities in the energies of successive stimuli. Experiment VI examines whether such an inequality effect is found in the event perception paradigm.

1.5 General methods

Apparatus: The experiments were conducted on - line to a PDP 11/45 computer manufactured by the Digital Equipment Corporation. Stimuli were presented on a Decgraphic 11 GT40 visual display unit (see Figure 1.3). A chin rest was provided which fixed the viewing distance of the screen at 49 cm. At this distance the viewing area of the screen subtended $26^{\circ}36'$ horizontally by $21^{\circ}12'$ vertically. Subjects responded

FIGURE 1.3

Apparatus used in all experiments. Left to right are:

the Decgraphic 11 GT40 visual display unit;

the masked keyboard;

the padded chin rest.

Fig 1.3 opposite legend on p 59

by pressing keys on a keyboard situated immediately in front of them. For all experiments except experiment IV the keyboard was masked allowing subjects a choice of only two keys. The GT40 was situated in a cubicle isolated from the host computer, thus subjects worked alone.

The timing characteristics of the apparatus were checked independently using two photodiodes linked to a CRT oscilloscope. The writing speed of the GT40 was found to be within the manufacturer's specifications and software generated refresh intervals were found to be accurate to within one millisecond. The same equipment was used to investigate the decay characteristics of the GT40 phosphor. The first experiment employed a P39 phosphor with a JEDEC registered time of 150 msec to fall to 10% of maximum brightness, second and subsequent experiments used a much faster P31 phosphor with a registered time of 0.25 msec to fall to 1% of maximum (Bell, 1970). Use of the photodiodes indicated that both phosphors had a fast initial decay and verified the published decay rates. Nonetheless informal observation suggested that even the faster phosphor showed persistence for well beyond the published times when the display intensity was high and background illumination was low. Evidently there is a tail of phosphorescence which persists at less than 1% but which under these conditions is easily visible. The following precautions were therefore taken to ensure that this tail was below contrast threshold. Firstly, the experiments were carried out with light adapted subjects. Ambient illumination was supplied by a standard neon striplight; the luminance of the wall immediately behind the GT40 was approximately 12 ft 1 as measured by an SEI exposure photometer. Secondly the intensity of the display was kept at the minimum compatible with clear visibility of stimuli. It should be noted that the problem of source persistence is not peculiar to the use of CRT's: a similar problem with tachistoscopes has been reported by Mollon and Polden (1978).

Stimuli: Stimuli were random dot patterns generated by the host computer. The patterns were constructed by assigning points a random position within each cell of a notional M x M matrix. The details of pattern generation are as follows: The notional matrix was assigned M columns and M rows and each cell given a side of length L. The matricewas centred in relation to the screen centre and the x and y co-ordinates of the top left hand corner of cell (1, 1) were computed. A random proportion of L was then added to the x co-ordinate and a different random proportion of L subtracted from the y co-ordinate. The first dot in the pattern was plotted at the resulting co-ordinates. The process was repeated for cell (1, 2) and so on until the matrix was full. For the second and subsequent experiments a protection feature P was added which prevented dots from overlapping. This was achieved simply by subtracting P from L before the random proportion was computed.

The properties of a random pattern generated in this manner can easily be derived from or determined by its basic parameters. The number of elements in the pattern = M x M. The plotting area or size of the pattern = (M x L) x (M x L). The average horizontal and vertical separation between dots = L. The minimum separation between dots = P. All sizes and separations cited in the text were calculated in the above manner For all experiments except the first the value of P was 7.25' at the viewing distance of the screen. The computation time for a pattern containing 1024 dots was 6.9 seconds.

Each dot in the pattern subtended 4.8' and, unless otherwise stated, had a luminance of approximately 10 ftL. The screen on which points were plotted had a luminance of 1.6 ftL. The points were light green in colour: P39 and P31 phosphors peak at 4750 angstrom units and 5200 angstrom units respectively (Bell, 1970).

In the text the terms t_1, t_2 and ISI are used to refer to the duration of the first pattern of a sequence, the duration of the second pattern and the interval between the two patterns respectively. These terms are to be defined in relation to the timing characteristics of the visual display unit. Stimuli presented on a VDU achieve the appearance of continuity by successive paintings or refreshes of points on the display surface. The term 'refresh interval' refers to the time between successive refreshes of the same points on the screen. During the refresh interval points are plotted at the maximum rate of the computer, which for the present experiments was 20 to 30 microsec per point. The time taken to refresh the entire pattern is the refresh duration. The refresh duration must be equal to or less than the refresh interval. Thus the basic unit of timing for the VDU is the refresh interval. The only completely satisfactory method of defining the duration of a pattern on the screen is by giving the value of the refresh interval and the number of refreshes accorded to the pattern. However, it is often desirable to give durations as a continuous measure. For this purpose the onset of a pattern is defined as the time of the first refresh accorded to it and the offset is defined as the time of the last refresh accorded to it. Thus exposure duration = refresh interval x (number of successive refreshes - 1). Similarly ISI is defined as the interval between the last refresh of pattern 1 and the first refresh of pattern 2.

Within each experiment in the present study the refresh interval was constant. For experiments I - IV the refresh interval was 20 msec and for experiments V - VII the refresh interval was 5 msec. For all experiments except III (variable ISI) and VI (variable t_1 and t_2) the onset of the second pattern occurred 500 msec after the onset of the first pattern. For experiments I, II and IV this was achieved by giving pattern 1 25 refreshes at 20msec intervals (t_1 = 480msec, ISI = 20 msec); for experiments V and VII it was achieved by giving pattern 1 100 refreshes at 5 msec intervals (t_1 = 495 msec, ISI = 5 msec).

The experiments employed a fixation cross which subtended 35.4' by 35.4' and had a luminance of approximately 6.3 ftL.

CHAPTER 2: DETECTION OF EVENTS

The following experiments are concerned with the ability to detect the appearance and disappearance of single dots in random dot patterns. A very similar rationale underlies Experiment I and II. Both experiments investigate whether limits to the ability to detect events are reached when steady state properties of the stimulus array are varied. Furthermore both experiments test aspects of integration and/or differentiation models of event detection. Experiment III, on the other hand, seeks to determine whether the present event detection task can be performed over ISIs similar to those reported in previous studies and also whether pattern complexity affects the decay of the storage underlying event detection.

2.1 Experiment I: The effect of number of elements, size of array and separation between elements on event detection

The aim of the first experiment was to identify some of the limits of the ability to detect events. The subjects' task was to detect the appearance and disappearance of single dots in random dot patterns. The experiment investigated the effect on this task of manipulation of some relatively simple properties of the stimulus array: number of dots, pattern size and separation between dots. These parameters were varied over the maximum range practicable given the available display system. The types of pattern employed are shown in Figure 2.1. The number of dots in the patterns varied from 16 to 1024, pattern size varied from $4^{\circ}38' \times 4^{\circ}38'$ to $17^{\circ}57' \times 17^{\circ}57'$ and average separation between dots varied from 8.4' to $4^{\circ}38'$.

FIGURE 2.1

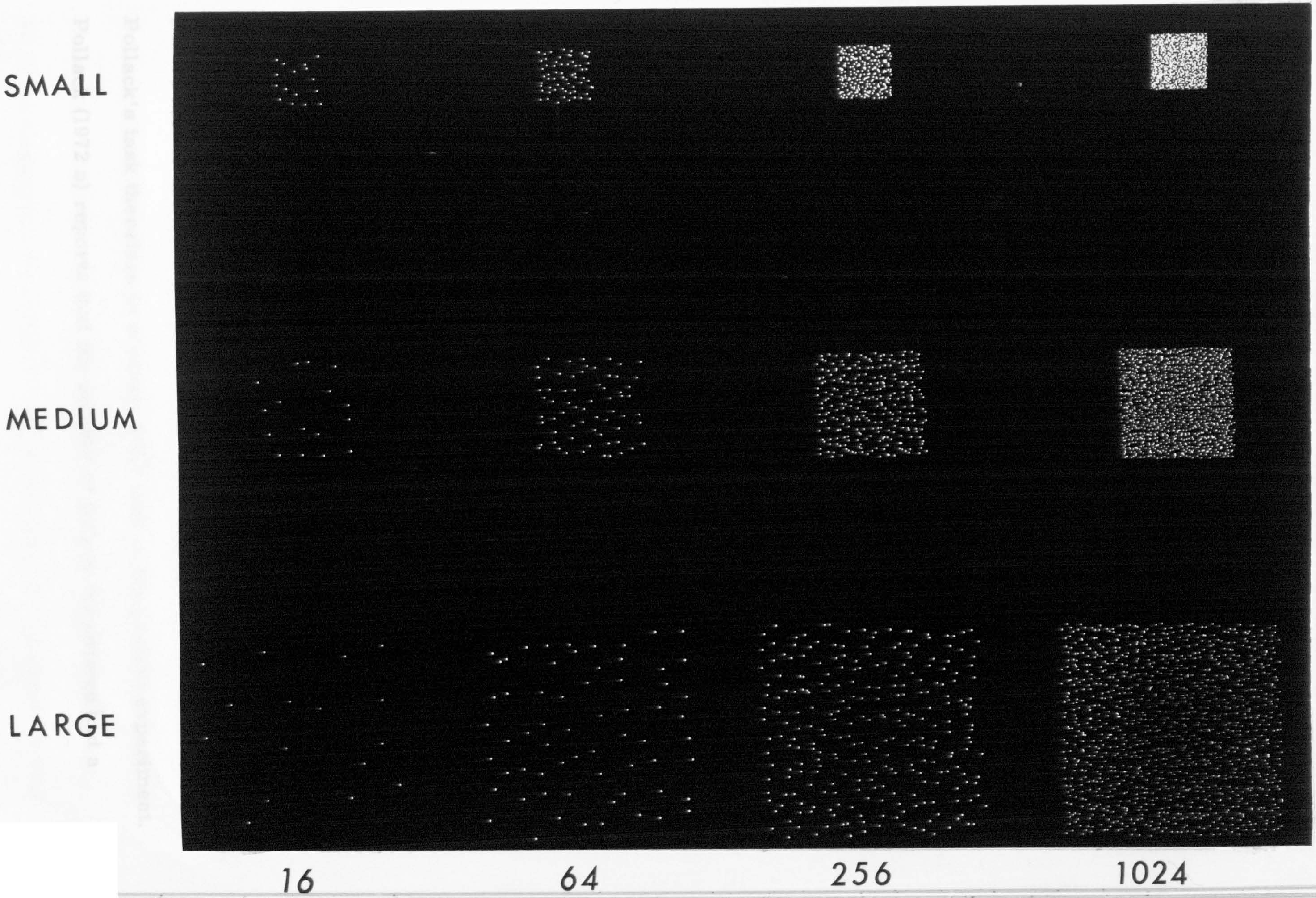
Examples of types of pattern used in Experiments I - III.

The twelve types of pattern were formed from a combination of 3 different sizes of pattern: small (4°38' x 4°38'), medium (9°12' x 9°12'), and large (17°57' x 17°57') and 4 different numbers of dots: 16, 64, 256 and 1024. Patterns with equal average separation between dots lie along the diagonals from upper left to lower right.

All twelve types of pattern were employed in Experiment I. The patterns which were employed in Experiments II and III had an added feature which prevented dots from overlapping.

The patterns are considerably reduced from physical size. The sizes given in terms of angle subtended are correct at a viewing distance of approximately 13 cm.

Fig 2.1 [illegible] located on p 65



The experiment allows a test of the differentiation hypothesis. In so far as differentiation theory implies that the visual system is particularly designed to detect changes it predicts that the level of performance in an event detection task will be relatively high. Furthermore, differentiation theory proposes that sudden changes are enhanced and steady state stimuli suppressed. Thus manipulation of the steady state properties of the stimulus array should, on this theory, have relatively little effect on performance of an event detection task. Thus differentiation theory predicts that overall performance in the present experiment should be high and relatively unaffected by manipulation of pattern parameters. Integration theory, on the other hand, does not yield specific predictions concerning the performance to be expected in the present experiment.

Pollack (1972 a, b) reports results which have a bearing on the above predictions. Pollack studied apparent motion of dots in random dot patterns. One of the tasks employed by Pollack required subjects to detect whether or not a dot had been displaced in successive random dot patterns. Displacement was produced by deleting one dot from the first pattern to be presented and adding another dot in a different position in the second, otherwise identical, pattern. As Bell and Lappin (1973) have pointed out, this task does not actually require motion perception but simply detection of a disappearance and/or an appearance. Pollack's task therefore is similar to the task in the present experiment. Pollack (1972 a) reports that the number of dots in the pattern had a large effect on performance of this detection task: increasing the number of dots in the pattern from 4 to about 100 (Pollack is not specific) resulted in a decrease in performance from 85% correct to just greater than chance. Pollack (1972 b) confirms this effect in several other experiments. As it stands this result appears to argue against a differentiation theory of event detection. However, it should be noted that Pollack used very short presentation durations: first and second pattern durations were the same and equal to 12 msec. He also employed an ISI of 64 msec which he found gave optimum performance with these presentation durations. The use of short presentation times and an ISI between patterns is important because the predictions concerning differentiation theory refer to the effects of sustained stimuli. An effect of number of pattern elements similar to that reported by Pollack would thus be inconsistent with a differentiation hypothesis only if it were obtained at long exposure durations with a short or no ISI.

Evidence that pattern complexity does not affect performance of an event detection task at long exposure durations and short ISIs has been presented by Phillips (1974) in a study discussed above. The first pattern in Phillips' display sequence was presented for 1 sec while the second was displayed until the subject responded. Phillips reports that at ISIs of 20 msec performance for 8 x 8 matrices of squares was not significantly different from performance for 4 x 4 matrices. However, the 8 x 8 matrices employed by Phillips had a mean of only 32 filled elements. Thus the failure to find an effect in this case may have been due to the relatively small number of elements in the patterns.

The patterns in the following experiment had a maximum number of elements far greater then the patterns employed by either Pollack or Phillips. The duration of the first pattern in the display sequence was 480 msec, there was an ISI of 20 msec, and the second pattern was displayed until the subject responded. In addition to allowing a test of the differentiation hypothesis it was also considered that such a presentation sequence would give results which were more comparable with normal visual input than results obtained with, for example, Pollack's presentation procedure.

Method

Subjects: Subjects were 26 Stirling University undergraduates with normal or corrected to normal vision. Participation fulfilled a course requirement.

Stimuli: The twelve types of pattern comprising the main manipulation of Experiment I are shown in Figure 2.1. The twelve types of pattern were formed from a combination of 3 different sizes of pattern: small ($4^{o}38' \times 4^{o}38'$), medium ($9^{o}12' \times 9^{o}12'$) and large ($17^{o}57' \times 17^{o}57'$); and 4 different numbers of dots: 16, 64, 256 and 1024. The upper limits on the size of pattern and the number of dots in the pattern reflect the capabilites of the GT40 display system. Dot density is naturally confounded with number of dots and size of pattern. No attempt was made to unconfound these factors. However, values of number and size were chosen to limit the range of different average separations between dots to 6: 8.4', 16.8', 34.8', $1^{\circ}9.6'$, $2^{\circ}19'$ and $4^{0}38'$. In Figure 2.1 patterns with equal density lie along diagonals from upper left to lower right. Because of a trend which was apparent in the data a further three types of pattern were added for the final 12 subjects. These patterns had a density equal to that of the most dense of the original twelve patterns (N = 1024, size: small, separation = 8.4'). The patterns consisted of 16, 64 and 256 dots plotted within 34.8' x 34.8', $1^{\circ}9.6'$ x $1^{\circ}9.6'$ and $2^{\circ}19'$ x $2^{\circ}19'$ respectively. These patterns had an average separation between dots of 8.4'.

A new pattern was generated on each trial. A target dot was selected at random from among the dots in the pattern generated on a given trial. Examples of a random dot pattern with and without a target dot are shown in Figure 1.1 (a) and (b) respectively (see page 5). The values of number of dots given above include the target dot. There were two types of event:

(a) Appearances: a pattern without a target dot followed by the same pattern with a target dot. For example, Figure 1.1 (b) followed by Figure 1.1(a).

(b) Disappearances: a pattern with a target dot followed by the same pattern without a target dot. For example, Figure 1.1(a) followed by Figure 1.1(b).

On trials on which there was no event a target dot was not selected and the first and second patterns were identical. On all trials the value of t_1 was 480 msec achieved by 25 refreshes at 20 msec intervals. There was an ISI of 20 msec and t_2 was variable.

Procedure: At the commencement of the experiment the subject read a printed sheet of instructions. The subject sat in front of the display terminal with each hand on a key of the masked key board. The subject was informed that reaction time was being recorded but emphasis was placed on responding correctly. The subject was instructed to ensure that his chin was on the chin rest and that he was fixating the cross displayed on the screen before initiating each trial. A trial consisted of the following sequence: The subject initiated the trial by pressing the right hand button on the keyboard. The fixation cross was removed and followed by a blank interval of 100 msec. The sequence of random dot patterns was then displayed. The subject's task was to indicate whether there had or had not been an event on that trial. An event occurred on exactly half the trials. Subjects responded by pressing a button marked "event" (right hand) or "no event" (left hand) Reaction time, as measured from the onset of the second pattern, and response were recorded automatically. The subject's response terminated the pattern currently being displayed. The machine indicated readiness for a new trial by re-displaying the fixation cross. The interval between the subject's response and the re-display of the fixation cross was variable and dependent on the number of dots in the next pattern to be displayed. This interval was always less than ten seconds.

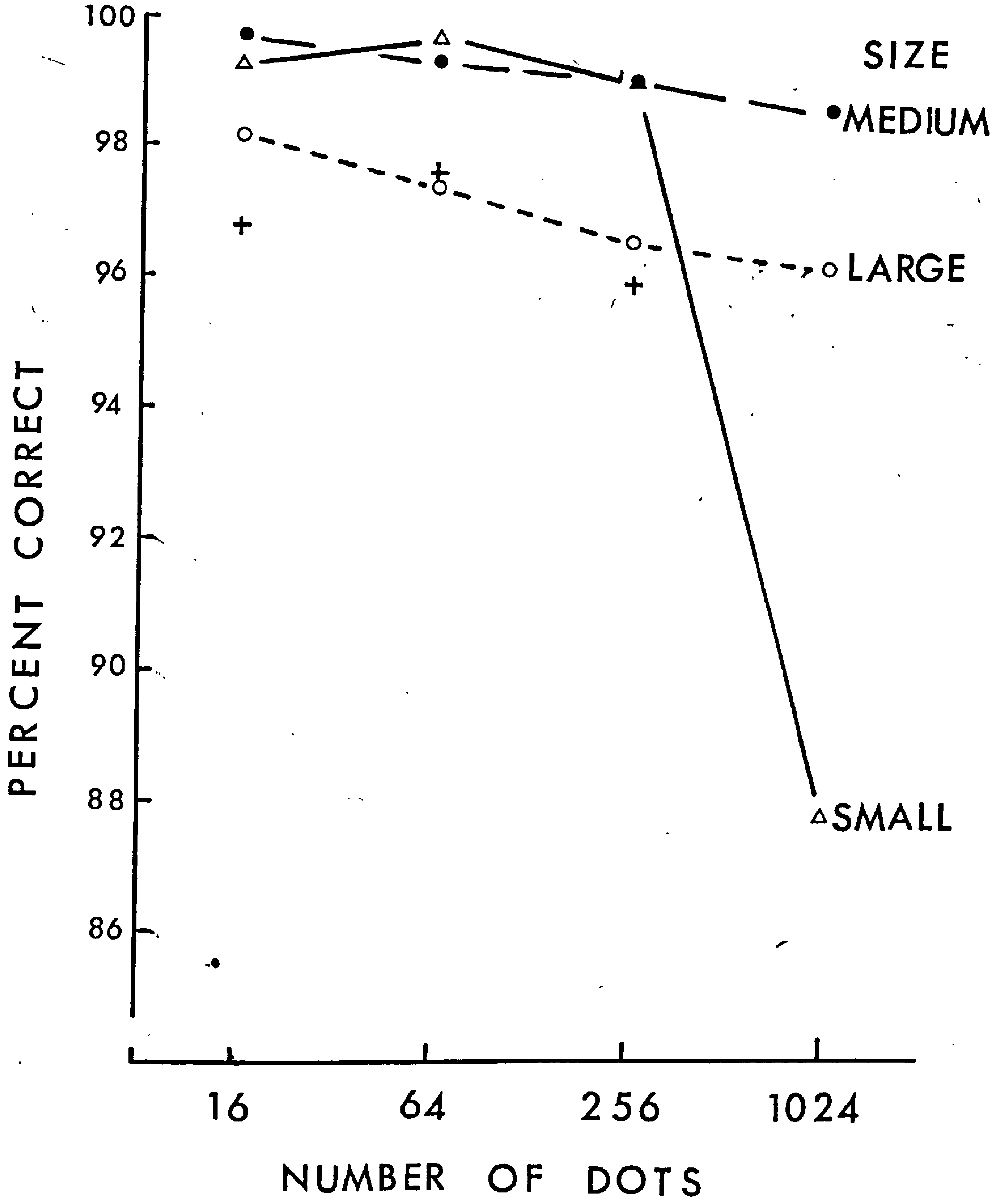
The experiment was conducted in two halves: appearances in one half and disappearances in the other. Subjects were informed of the order in which the two halves would occur and the mid point in the experiment was indicated by the machine. The order of type of event was counterbalanced across subjects. The two types of event by either twelve types of pattern or fifteen types of pattern gave a total of 24 conditions for the first 14 subjects and 30 conditions for the final 12 subjects. Subjects performed 10 trials per condition: 5 event and 5 no event trials. The presentation order of trials was determined by random selection without replacement from the total set of trials within each half of the experiment. To ensure familiarity with the task and procedure there was a practice at the beginning of each session consisting of 2 trials under each exposure condition.

Results

An examination of the results revealed no important differences between subjects. The data obtained from all S's were therefore pooled. The percentages of correct response, over all S's, are shown in Figure 2.2 for (a) appearances and (b) disappearances as a function of the number of dots in the pattern and pattern size. Each point respresents 260 observations. It should be remembered that although performance is plotted in this Figure as a function of number of dots and pattern size, a further potentially confounding factor is separation between dots. Also plotted is performance for the three additional patterns with a density equal to the densest of the original patterns.

FIGURE 2.2(a)

Experiment I. Appearances. Percentages of correct response as a function of pattern size and number of dots in the pattern. Lines join points representing patterns of equal size. The three additional patterns with densities equal to the densest of the original patterns are also plotted (+). Chance performance (not shown) is 50% correct.



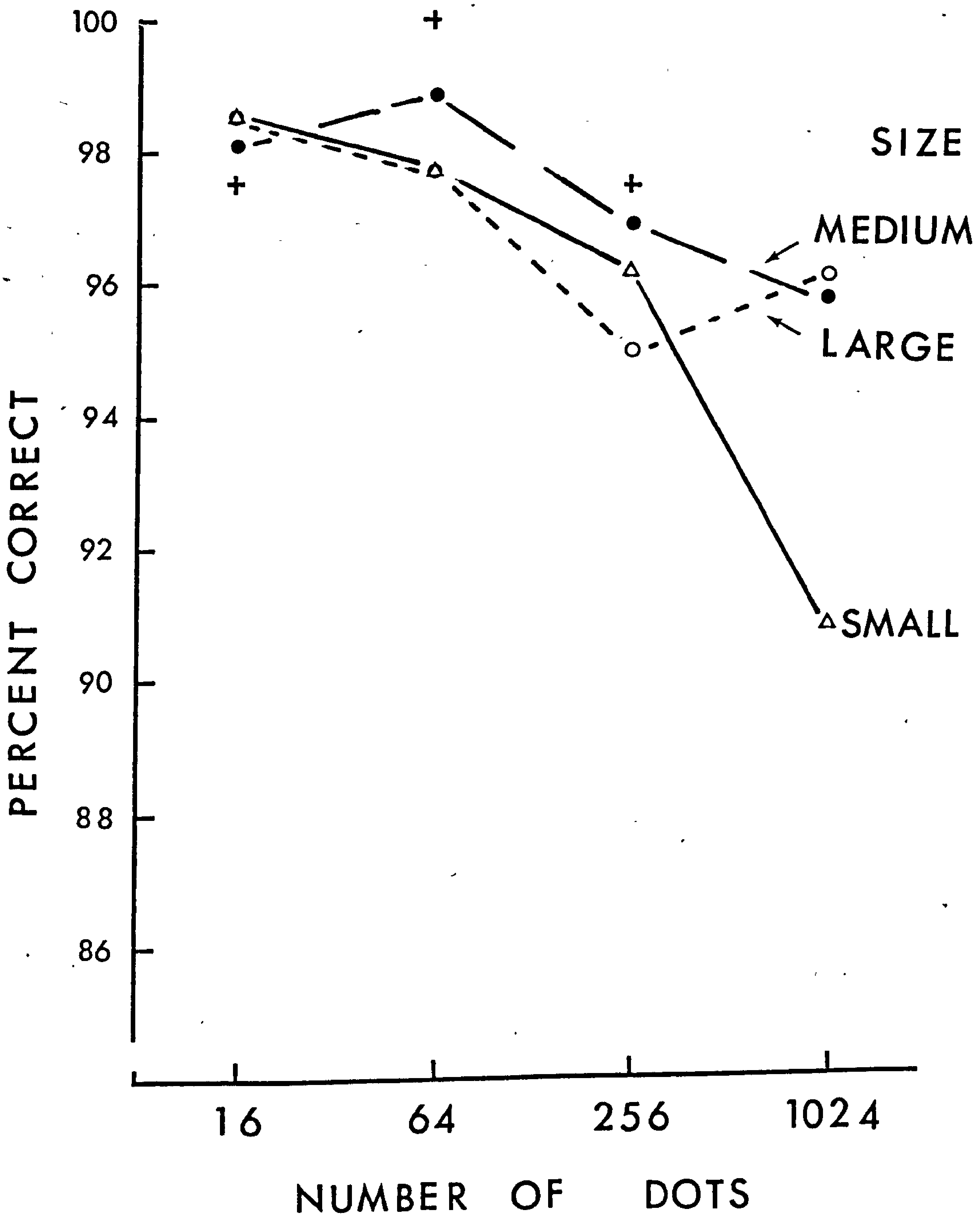
(a) APPEARANCES

Fig. 2.2 (a) opposite legend on p72

FIGURE 2.2 (b)

Experiment I. Disappearances. Percentages of correct response as a function of pattern size and number of dots in pattern. Lines join points representing patterns of equal size. The three additional patterns with densities equal to the densest of the original patterns are also plotted (+). Chance performance (not shown) is 50% correct.

Fig 2. 2(b) opposite legend on P 73



(b) DISAPPEARANCES

Each point represents 120 observations. Here size of pattern is a potentially confounding factor. As can be seen, the overall level of performance is very high. For example, with medium size patterns containing 1024 dots performance for appearances was 98% correct. Chance performance, which is not shown in Figure 2.2, is 50% correct. The lowest percentages recorded for appearances and disappearances were 88% and 91% respectively, both obtained with the densest of the original twelve patterns ($N = 1024$, size: small, separation = 8.4'). This performance is still well above chance.

A repeated measures analysis of variance was performed on the number of correct responses. The analysis followed the original design of the experiment; two types of event (appearances and disappearances) by three sizes of pattern (small, medium and large) by four numbers of dots (16, 64, 256 and 1024) by 26 subjects. Summary tables of this and all other major statistical analyses are given in Appendix 2. Again, it should be remembered that separation between dots is a potentially confounding factor. There was a significant difference between performance for appearances and disappearances $F(1, 25) = 4.45$, $p < 0.05$, performance for disappearances being slightly poorer than performance for appearances. There was also a small but significant effect of number of dots $F(3, 75) = 20.4$, $p < 0.001$. As is evident in Figure 2.2 (a) and (b) there is slight decrease in performance with increase in number of dots. Finally, there was significant effect from size of pattern, $F(2, 50) = 9.0$, $p < 0.001$, and a significant interaction between size of pattern and number of dots in pattern, $F(6,150) = 8.3$, $p < 0.001$. This interaction is evident in Figure 2.2 as a discontinuity in the curves for the small pattern size: performance for the densest pattern ($N = 1024$) appears to be depressed in relation to performance for the other patterns of this size. If this effect was simply due to the density of this pattern, performance for the three additional patterns of equal density would be expected to be at a similar level. However, for both appearances and disappearances performance for the three additional patterns was significantly better than performance for the densest of the original patterns (Z test, $\alpha = 0.05$). Thus it would appear that this significant interaction is not a simple effect of density. No other interactions were significant.

Mean reaction times for correct "event" responses are shown in Figure 2.3 for (a) appearances and (b) disappearances as a function of pattern size and number of dots in the pattern. As in Figure 2.2, separation between dots is a potentially confounding factor. The 0.05 confidence limits for the means of the small size pattern are indicated. (The 0.05 confidence limits for the other means are to be found in Appendix I, together with other data from this and the following experiments). The three additional patterns with a density equal to that of the densest of the original patterns are also plotted.

FIGURE 2.3

Experiment I. Mean reaction times for correct "event" responses for (a) appearances and (b) disappearances as a function of pattern size and number of dots in the pattern. Lines join points representing patterns of equal size. The 0.05 confidence limits for the small size pattern are indicated. The three additional patterns with densities equal to that of the densest of the original patterns are also plotted (+).

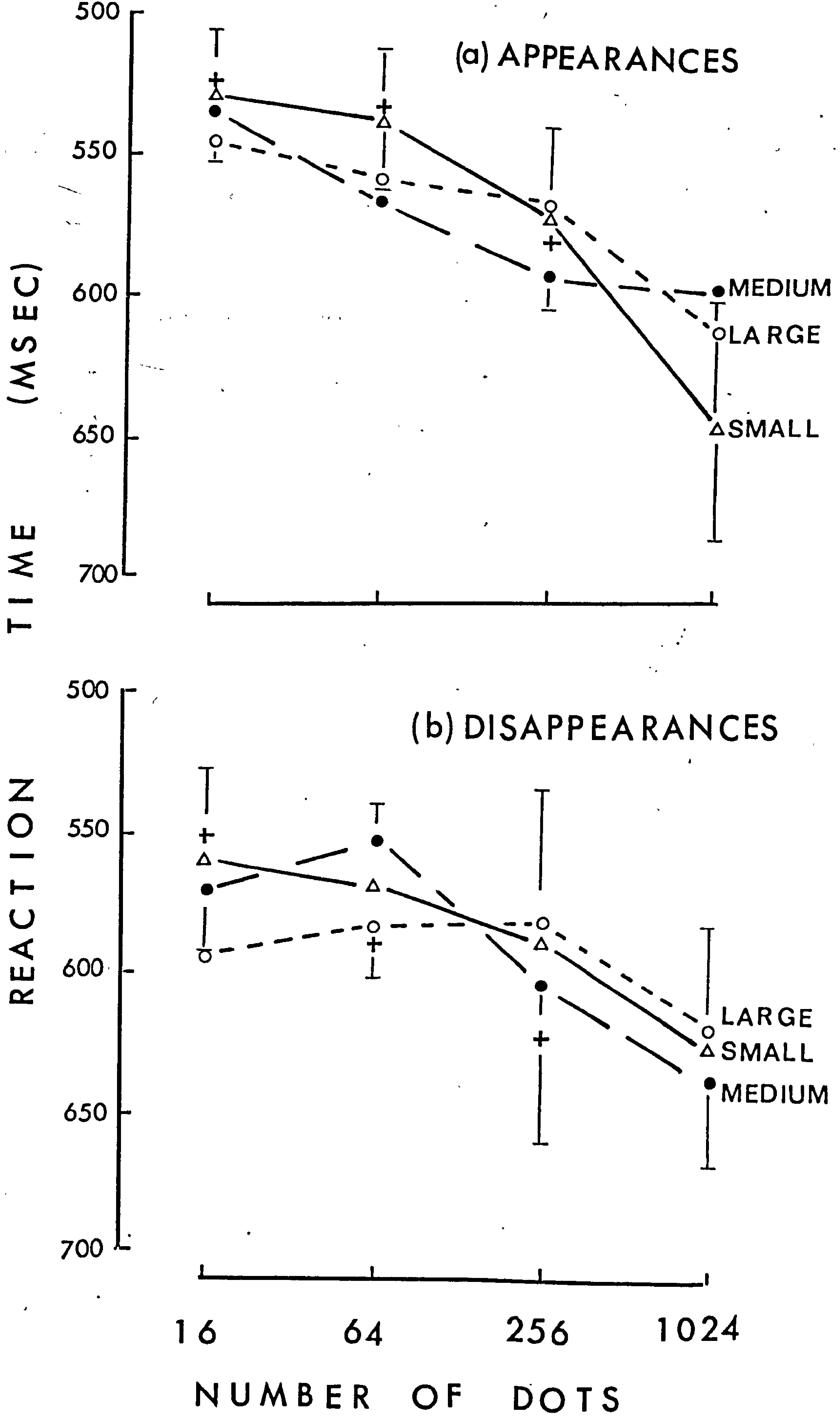


Fig 2.3 opposite (legend on p.76)

The results for reaction times are broadly similar to those for percent correct. Reaction times to appearances were significantly faster than reaction times to disappearances (T = 10, N = 12, $p < 0.05$ on the Wilcoxon test). There was also an overall tendency for reaction times to increase as number of dots increased (T = 0, N = 6, $p < 0.05$).

Discussion

The aim of the experiment was to identify limits to the ability to detect events. However, under no condition in the present experiment did performance fall to threshold. The overall picture is of a very high level of performance maintained over a wide range of manipulations of the stimulus array.

The only condition approaching a limit to performance was that in which 1024 dots were plotted within $4^{o}38' \times 4^{o}38'$. Individual dots in this type of pattern were not always disciminable from one another. The method of pattern generation allowed dots to overlap to almost half their diameter (for later experiments a constraint was added which made this impossible). Such overlapping was much more likely in this pattern than in the other patterns used in the original design. Thus subjects may have been detecting or failing to detect small changes in intensity rather than the appearance or disappearance of isolated dots. Even here, however, the effect does not appear to be due to density alone but to density combined with number of dots and/or pattern size.

The results support the view that the ability to detect events is highly developed and can function with complex and detailed stimulation. The results for the densest of the original patterns are not necessarily inconsistent with the view that the event detection system serves to signal significant change in the natural environment. Clearly there must be some limits to the ability to detect change. In fact, it is probably not advantageous to be sensitive to extremely small intensity changes in complex stimuli. Thus one might expect a threshold which excluded the signalling of such changes.

The results favour an explanation of event detection in terms of differentiation: a high level of performance was obtained which was largely independent of the manipulation of steady state parameters of the stimulus array. It was suggested that the results for the densest pattern might reflect the ability to disciminate small changes in intensity rather than the appearance or disappearance of isolated dots. Even for these patterns, however, performance was still well above chance. It would in fact be difficult to explain the overall level of performance observed in this experiment without assuming some kind of special purpose. process for detecting change.

Finally, the results obtained in the present experiment are in agreement with those obtained by Phillips (1974) rather than those of Pollack (1972 a, b). Phillips argues that the high level of performance achieved with his 8 x 8 matrices is evidence that the storage underlying the ability to detect differences in successive patterns is high capacity. The results of the present experiment suggest that this storage is indeed of very high capacity, as a pattern containing 1024 dots can be handled with little loss. The question of whether pattern complexity affects the decay of this storage will be examined in Experiment III.

2.2. Experiment II: The effect of inhomogeneity in the luminance of elements on event detection

The rationale for the second experiment follows closely that for Experiment I. The first experiment investigated the effect of number of dots, size of pattern and separation between dots on event detection: the second experiment extends this investigation to ask whether variation in the luminance of the dots in the pattern affects performance.

The experiment was designed to test the integration and differentiation hypotheses. It was suggested above that, on an integration model, an area of change is identifiable because, for a certain period, it is in transition from sustained to background levels of response or vice versa. It was also suggested that this transition may be evident in the apparent brightness of an area of change. It was noted, for example, that Haber and Hershenson (1974) conceptualize persistence as an apparent fading from view. Thus on one interpretation of an integration hypothesis areas of change have an intermediate brightness and are detectable by comparison with the brightness of surrounding areas. On this interpretation, if the surrounding areas occupy a range of luminances the comparison should be rendered more difficult and performance impaired. This form of the integration hypothesis therefore predicts that performance of an event detection task should be adversely affected by inhomogeneity in the luminance of pattern elements. On the other hand the differentiation hypothesis implies that events are enhanced and sustained stimuli suppressed. On this model the steady state properties of the stimulus array should have little or no effect on performance. The differentiation hypothesis therefore predicts that inhomogeneity in the luminance of pattern elements should have little or no effect on performance of an event detection task.

Method

Subjects: Subjects were 14 staff and student volunteers from the Department of Psychology, University of Stirling. Their vision was either normal or correct to normal.

Stimuli: The experiment employed four types of pattern similar to four of the patterns used in Experiment I and shown in Figure 2.1 (see page 65). The four types of pattern were formed from a combination of two different sizes of pattern: medium ($9^{0}12' \times 9^{0}12'$) and large ($17^{o}57' \times 17^{o}57'$); and two different number of dots: 64 and 265. A feature was added to the pattern generation algorithm which set the minimum separation between dots at 7.25'. Pattern luminance could be either uniform or variegated. When pattern luminance was uniform the luminances of all dots in the pattern were the same and equal to approximately 10 ft L as measured by an SEI exposure photometer. When patterns were variegated, each component dot assumed at random one of four luminance levels: 6.3 ft L, 10 ft L, 11.3 ft L and 11.6 ft L. These luminances represent four consecutive programmable intensity levels and were the maximum range of luminances it was practicable to obtain with the display system. Dots with a luminance of 6.3 ft L appeared dim but still visible while dots with a luminance of 11.6 ft L appeared very bright. The overall appearance of variegated patterns was strikingly piebald.

As in Experiment I the target dot was selected at random from among the dots in the pattern generated for any given trial. The luminance of the target dot was always 10 ft L. There were two types of event appearances and disappearances. On all trials $t_1 = t_2 = 480$ msec achieved by 25 refreshes at 20 msec intervals. There was an ISI of 20 msec.

Procedure: The procedure for this experiment was very similar to that for Experiment I. The subject's task was again to indicate whether there had or had not been an event on a given trial. An event occurred on exactly half the trials. The sequence for each trial followed that of Experiment I except that the second pattern was terminated after 480 msec whether or not the subject had responded. The interval between the subject's response and the re-display of the fixation cross was variable but always less than three seconds.

The experiment was again conducted in two halves: appearances in one half and disappearances in the other. The order of the two types of event was counterbalanced across subjects. The two types of event by two numbers of dots by two pattern sizes by two luminance conditions gave a total of 16 conditions. Subjects performed 16 trials under each condition:8 event and 8 no event trials. The 14 subjects thus contributed a total of 224 observations per condition. Order of trials was determined by random selection without replacement from the total set of trials within each half of the experiment. There was a practice at the beginning of each session consisting of 8 trials under each condition. During the practice the machine indicated correct and incorrect responses.

Results

The percentages of correct response over all Ss, are shown in Figure 2.4 for (a) appearancesand (b) disappearances as a function of number of dots, pattern size and luminance condition. Chance performance, which is not shown in the Figure, is 50% correct. As in Experiment I performance under all conditions was high: percentages of correct response ranged from 95% to 99%.

A repeated measures analysis of variance was performed on the number of correct responses. The analysis followed the design of the experiment; two types of event by two pattern sizes by two numbers of dots by two luminance conditions by 14 subjects. None of the main

FIGURE 2.4

Experiment II. Percentages of correct response for (a) appearances and (b) disappearances as a function of number of dots, pattern size and luminance condition. Solid lines join points representing patterns of the same size with uniform luminance; broken lines join points representing patterns of the same size with variegated luminance. The size of pattern is indicated by type of point: x - medium, o - large. Chance performance (not shown) is 50% correct.

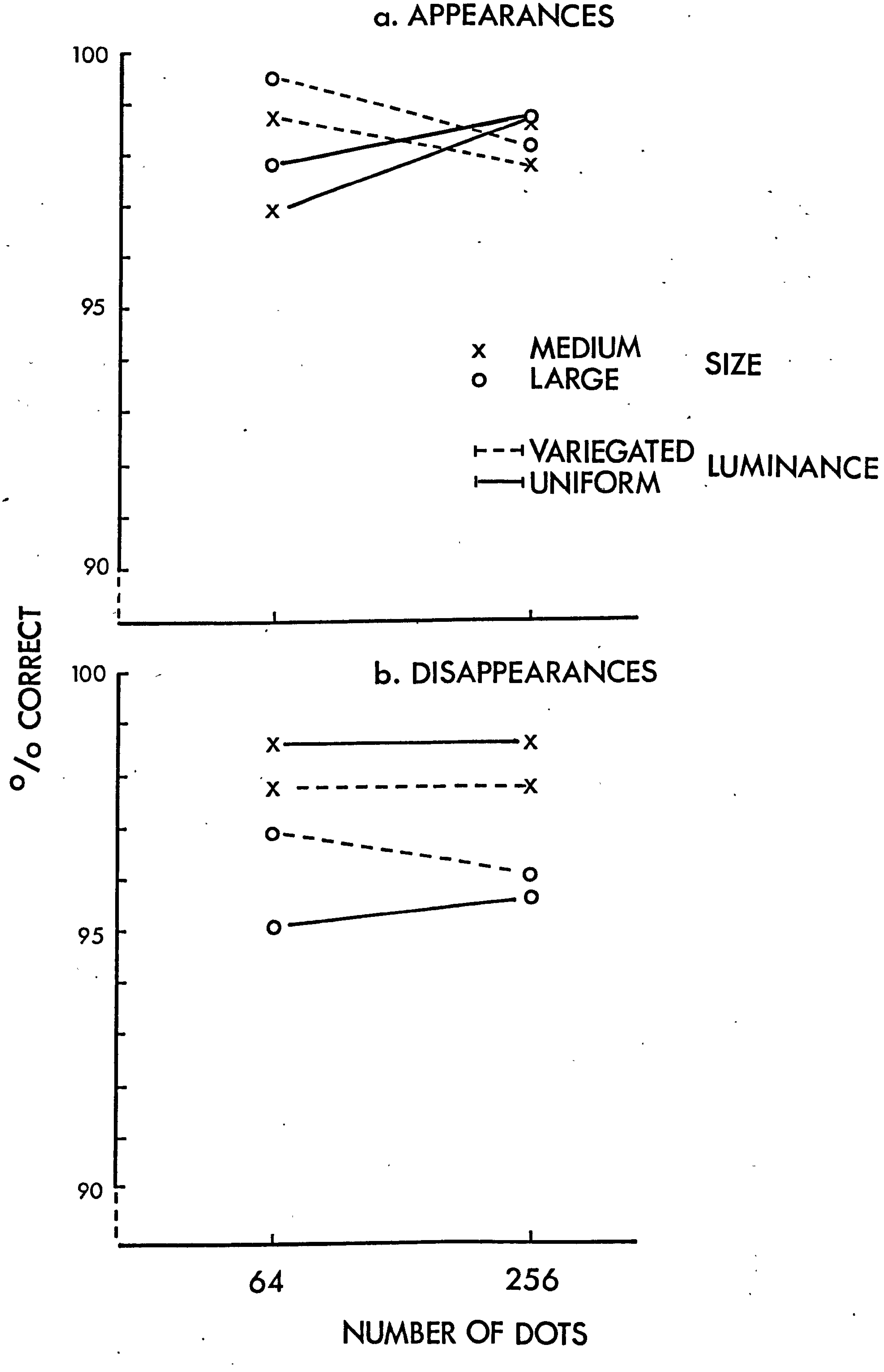


Fig 2.4 opposite legend on P 83

effects reached conventional levels of significance. The only interaction which was significant was that of type of event by pattern size, $F(1,13) = 6.99$, $p < 0.05$. For appearances performance with large patterns was slightly better (0.6%) than with medium size patterns, while for disappearances it was slightly poorer (2.3%).

The mean reaction times for correct "event" responses are shown in Figure 2.5 for (a) appearances and (b) disappearances as a function of number of dots in the pattern, pattern size and luminance condition. There was a nonsignificant trend towards shorter reaction times to appearances than disappearances. There was also a nonsignificant trend towards an increase in reaction time with increase in number of dots. There appear to be no systematic differences between reaction times for variegated and uniform patterns.

Discussion

The aim of the present experiment was to investigate whether inhomogeneity in the luminance of pattern elements affected performance of an event detection task. The results indicate that varying the luminance of pattern elements over the range employed in the experiment has little or no effect on an event detection task. Before considering the implications of this finding it is worth briefly comparing the results of this experiment with those of Experiment I.

Performance in the present experiment was at or near ceiling

FIGURE 2.5

Experiment II. Mean reaction times of correct "event" responses for (a) appearances and (b) (overleaf) disappearances as a function of number of dots, pattern size an luminance condition. Solid lines join points representing patterns of the same size with uniform luminance; broken lines join points representing patterns of the same size with variegated luminance. The size of pattern is indicated by the type of point: x - medium, o - large. The 0.05 confidence intervals for the patterns with varied luminance are indicated.

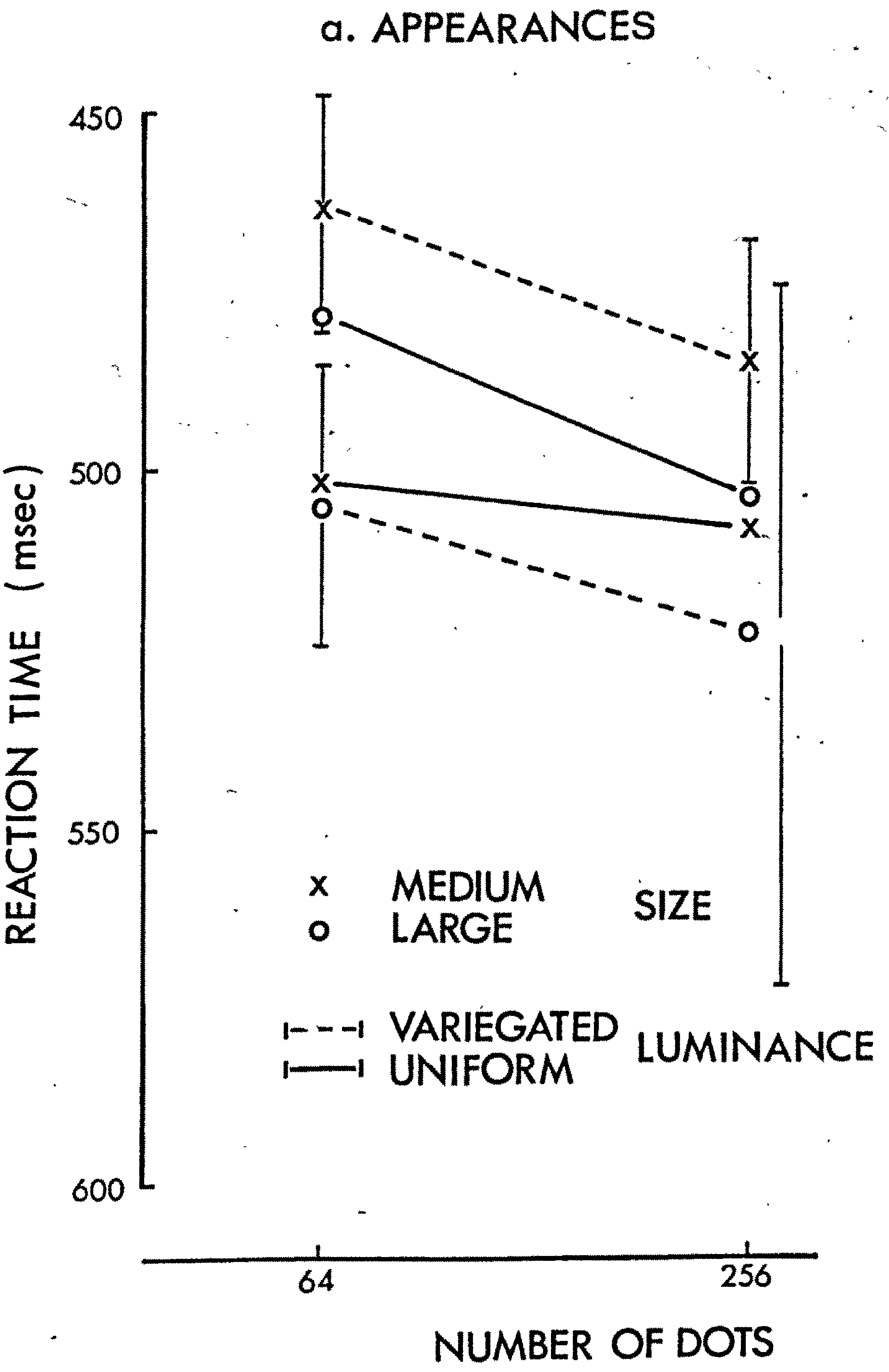
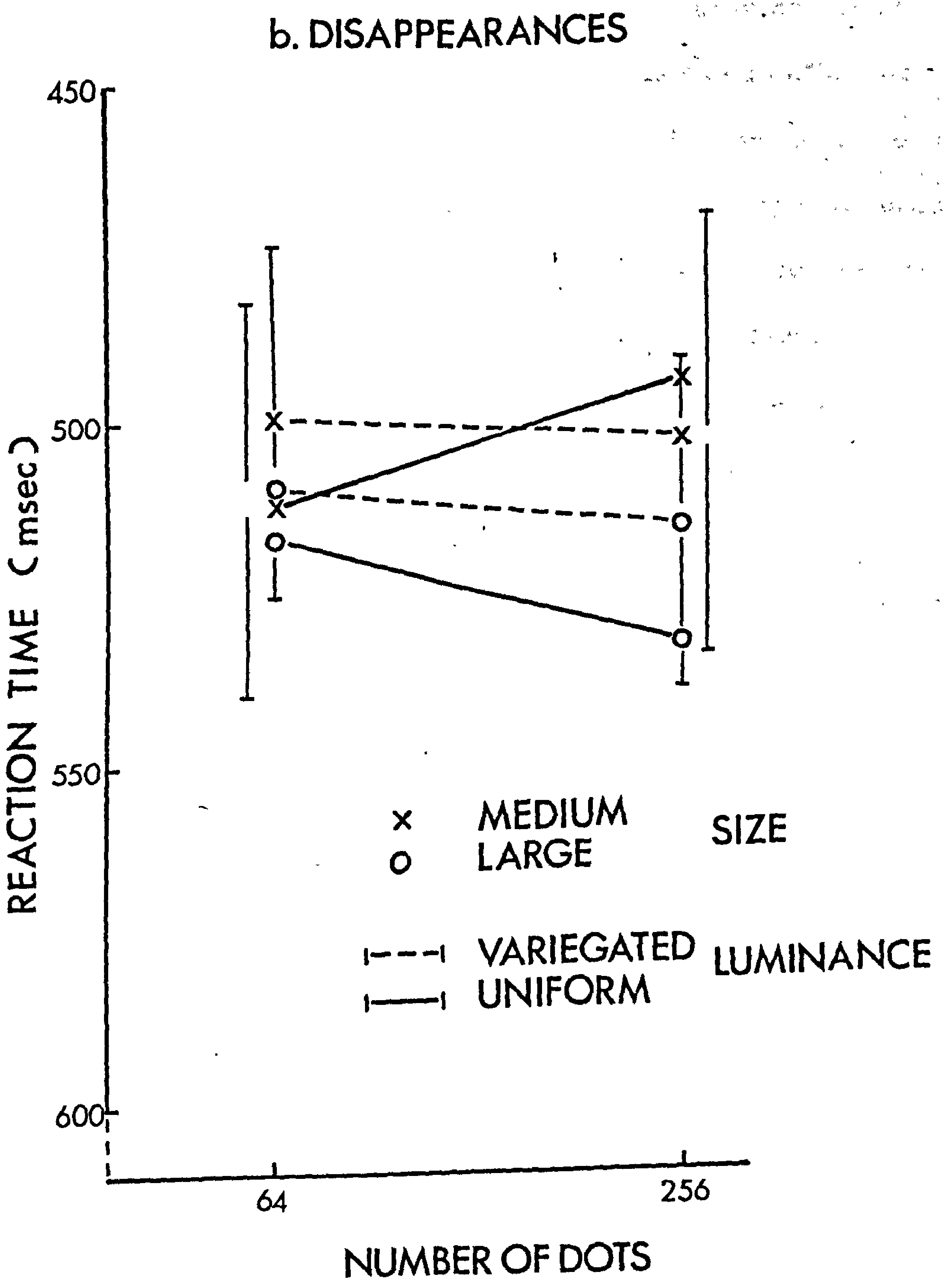


Fig 2.5 (a) opposite legend on p 85

Fig 2.5 (b) follows 2.5 (a) at P 85



under all conditions, thus confirming that a high level of accuracy is to be expected in an event detection task. The lack of an effect on number of correct responses of either number of dots or pattern size suggests that effects of these variables are difficult to replicate under the present procedure. Presumably effects of type of pattern were obtained in Experiment I because a greater range of patterns was employed. The finding that there was a significant interaction between type of event and pattern size in the present experiment is puzzling: such an effect was not found in Experiment I.

The overall level of performance achieved in the present task and the lack of an effect of variegating pattern luminance lend further general support to the view that an event detection system could serve to signal change in the natural environment. The range of intensities employed in the experiment was much smaller than that which would be encountered in many visual environments. Nonetheless if the event detection system were at all sensitive to such variations in stimulus luminance an effect of inhomogeneity would have been expected in the present experiment.

The failure to find an effect of variegating pattern luminance argues against the view that areas of change are identifiable because they assume an intermediate apparent brightness. The result therefore militates against the idea that events are detectable because integrative processes produce a gradual change in apparent brightness in response to an abrupt change in the stimulus. A cautionary note, however, should be added concerning the implications of this result for an integration hypothesis. The experiment employed only four levels of dot luminance. Thus, on an integration hypothesis, it is possible that the brightness of an area of change in the present experiment was discriminable from the brightness of surrounding areas. It would clearly have been preferable if a finer grading of luminance levels could have been achieved. Furthermore, although it is a common and plausible assumption that integrative processes are reflected in apparent brightness, it is possible that events are identifiable by being in some transitional state other than that of intermediate apparent brightness. Thus an integration hypothesis cannot be discounted on the basis of the present results. However, the failure to find an effect of pattern inhomogeneity favours an explanation of event detection in terms of differentiation. The differentiation hypothesis predicted that inhomogeneity would have little or no effect on performance of an event detection task. The results of the experiment therefore confirm this prediction.

2.3 Experiment III The effect of ISI and pattern complexity on event detection

Sensory storage is implicit in the integration and differentiation models examined in Experiments I and II. It was noted that the high level of performance that could be obtained with patterns containing

1024 dots in Experiment I was evidence that the storage underlying event detection was high capacity. The following experiment was designed to examine the storage involved in event detection in a more explicit manner. Performance in an event detection task was studied as a function of ISI between patterns and variation in pattern complexity (a 1024 dot pattern displayed within $17^{o}57'$ x $17^{o}57'$ versus a 16 dot pattern displayed within $4^{o}38'$ x $4^{o}38'$). The experiment is essentially a partial replication of studies by Phillips (1974) and Phillips and Singer (1974).

The study by Phillips (1974) has been discussed previously. Phillips presented results indicating that pattern complexity has little or no effect on performance of an event detection task at ISIs of 20 msec. The results of Experiment I can be regarded as being in general agreement with this claim. His results also suggest, however, that beyond 20 msec the initial rate of decay of the storage underlying event detection may depend on pattern complexity. The following experiment examines this possibility in more detail.

The study by Phillips and Singer (1974) has also been discussed above. Phillips and Singer found that appearances were detectable up to ISIs of 120 msec and disappearances were detectable up to ISIs of 60 msec. They suggest that one function of sensory storage may be to allow the detection of changes which take place during interruptions. The generality of this view clearly depends on the duration of interruption over which events can be detected. However, Lappin and Bell (1972) present evidence suggesting that this duration may be shorter than that reported by Phillips and Singer. Lappin and Bell's paradigm has been described previously; briefly, they found that performance of a task requiring utilization of differences between successive stimuli fell to chance at ISIs of only 30 msec under all conditions except that in which the intervening stimulus was a dark field. If this shorter period is more typical then the generality of the view advanced by Phillips and Singer would be much reduced. The following experiment therefore investigates the ISIs over which changes can be detected under present conditions of stimulation.

Method

Subjects: Subjects were 18 Stirling University undergraduates with normal or corrected to normal vision. Participation fulfilled a course requirement.

Stimuli: The experiment employed two types of pattern similar to two of the patterns used in Experiment I and shown in Figure 2.1 (see page 65). The patterns were either simple: 16 dots displayed within $4^{o}38' \times 4^{o}38'$, or complex: 1024 dots displayed within

$17^{o}57' \times 17^{o}57'$.

As in previous experiments the target dot was selected at random from among the dots in the pattern generated for each trial. There were two types of event.

a) Appearances: a pattern without a target dot followed by a pattern with a target dot.

b) Disappearances: a pattern with a target dot followed by a pattern without a target dot.

There were six inter-stimulus intervals: 22, 32, 52, 72, 112 and 262 msec. On all trials t_1 = 480 msec, achieved by 25 refreshes at 20 msec intervals; the second pattern was displayed until the subject responded.

Procedure: The procedure for this experiment was very similar to that for the previous experiments. Subjects were informed that reaction time was being recorded but emphasis was placed on responding correctly. The subject's task was again to indicate whether there had or had not been an event on a given trial. A change occurred on exactly half the trials. The sequence for each trial followed that of Experiment I except that the ISI between the two patterns was variable. During the ISI the screen was blank. As in Experiment I the subject's response terminated the display of the second pattern. The interval between the subject's response and the re-display of the fixation cross was set at 10 seconds to allow time for generation of the complex patterns.

The experiment was again conducted in two halves: appearances in one half and disappearances in the other. The order of the two types of event was counterbalanced across subjects. The two types of event by two types of pattern by six ISIs gave a total of 24 conditions. Subjects performed 8 trials under each condition, 4 event and 4 no event trials. The 18 subjects thus contributed a total of 144 observations per condition. Order of trials was determined by random selection without replacement from the total set of trials within each half of the experiment. There was a practice at the beginning of each session consisting of two trials under each condition.

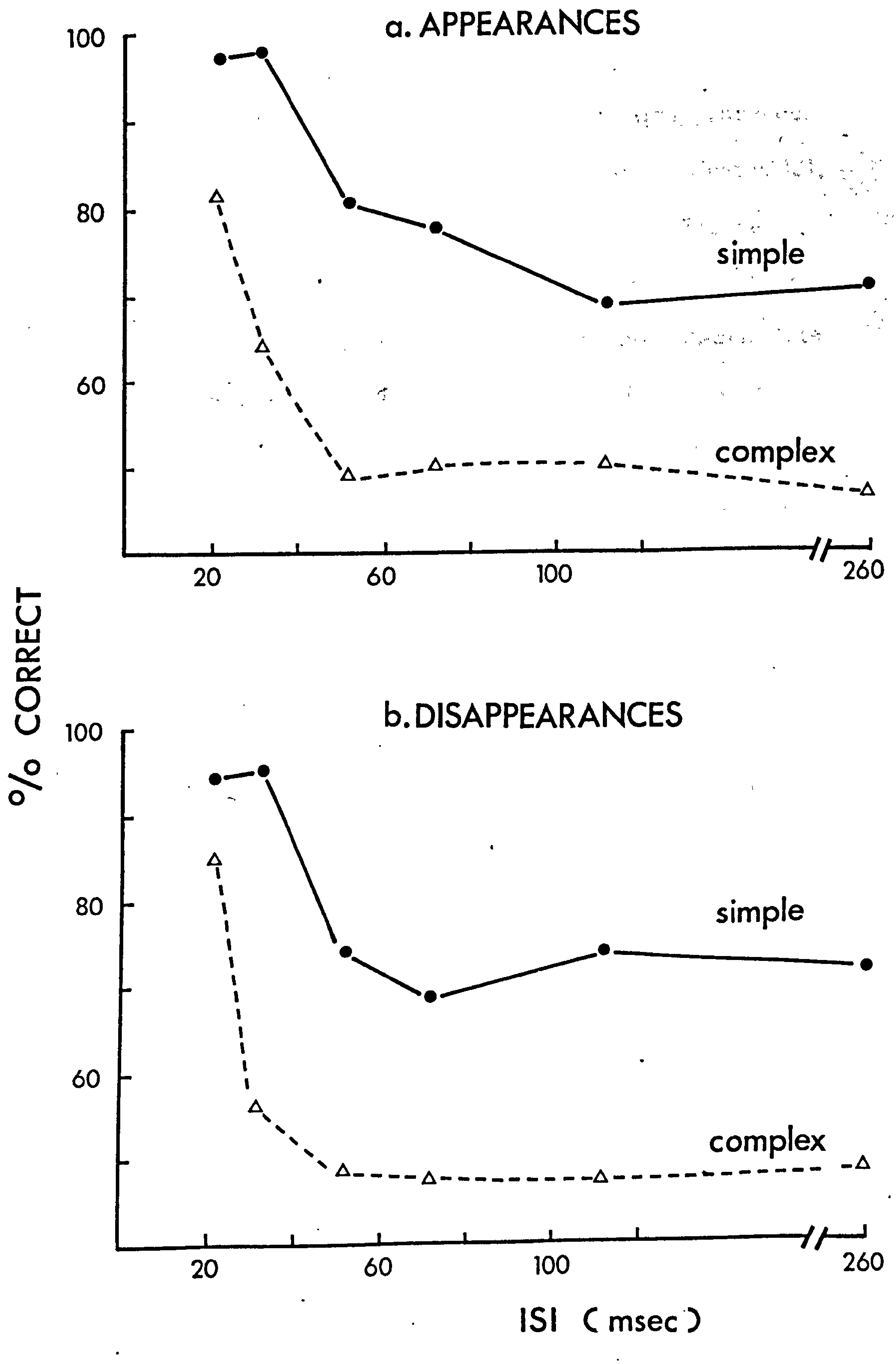
Results

Percentages of correct response are shown in Figure 2.6 for (a) appearances and (b) disappearances as a function of ISI and pattern complexity. A repeated measures analysis of variance was performed on the number of correct responses. The analysis followed the design of the experiment: two types of event by two types of pattern by six ISIs by 18 subjects. The effect of type of event was not significant, $F(1,17) = 1.26$, $p > 0.05$.

FIGURE 2.6

Experiment III. Percentages of correct response for (a) appearances and (b) disappearances as a function of ISI and pattern complexity. Simple patterns comprised of 16 dots plotted within 4°38' x 4°38' while complex patterns comprised 1024 dots plotted within 17°57' x 17°57'. Chance performance is 50% correct.

Fig 2.6 opposite legend on p 92



Thus overall performance for appearances and disappearances was very similar. There was a highly significant effect of ISI, $F(5,85) = 68.34$, $p < 0.001$. As can be seen from Figure 2.6 performance decreases as ISI increases; for three of the four type of event by type of pattern combinations an asymptote to performance appears to be reached between ISI values of 32 and 52 msec, the possible exception being performance for appearances in simple patterns. There was a highly significant effect of type of pattern, $F(1,17) = 420.02$, $p < 0.001$. The superiority of performance for simple patterns over complex patterns is evident at both long and short ISIs. At longer ISIs performance for complex patterns asymptotes at chance while performance for simple patterns appears to asymptote well above chance. At the shortest ISI employed in the experiment, 22 msec, performance was also reliably better for simple than for complex patterns (Z test, $\alpha = 0.05$). Comparison of Figure 2.6 with Figure 2.2 indicates that for both appearances and disappearances the differences in performance for simple and complex patterns at ISIs of 22 msec are much greater than those obtained in Experiment I between corresponding patterns. The analysis also indicated that there was a significant interaction between pattern complexity and ISI, $F(5,85) = 7.56$ $p < 0.001$.

A follow up analysis revealed that, averaged over type of event, this interaction was reliable at ISI values of between 22 and 32 msec (Scheffé criterion, $\alpha = 0.05$). As is apparent in Figure 2.6, performance for complex patterns decreases sharply between ISIs of 22 and 32 msec while performance for simple patterns shows little or no change.

Mean reaction times for correct "event" responses are shown in Figure 2.7 for (a) appearances and (b) disappearances as a function of ISI and pattern complexity. The 0.05 confidence limits for the simple patterns are indicated in the figure. Mean reaction times ranged from 720 to 1380 msec. There was a non significant trend towards faster reaction times for simple patterns. This trend is particularly evident at ISIs of between 22 and 52 msec. It should be noted that at longer ISIs there were far fewer correct "event" responses and thus the means are based on a smaller number of observations.

Discussion

Two questions were posed for the present experiment: firstly, whether the storage underlying event detection was affected by pattern complexity and secondly, over what period of interruption events were detectable under present conditions of stimulation. The results indicate that the effect of ISI on performance of an

FIGURE 2.7

Experiment III. Mean reaction times of correct "event" responses for (a) appearances and (b) disappearances as a function of ISI and pattern complexity. Simple patterns comprised of 16 dots plotted within $4^{\circ}38' \times 4^{\circ}38'$ while complex patterns comprised 1024 dots plotted within $17^{\circ}57' \times 17^{\circ}57'$. The 0.05 confidence limits for the simple patterns are indicated.

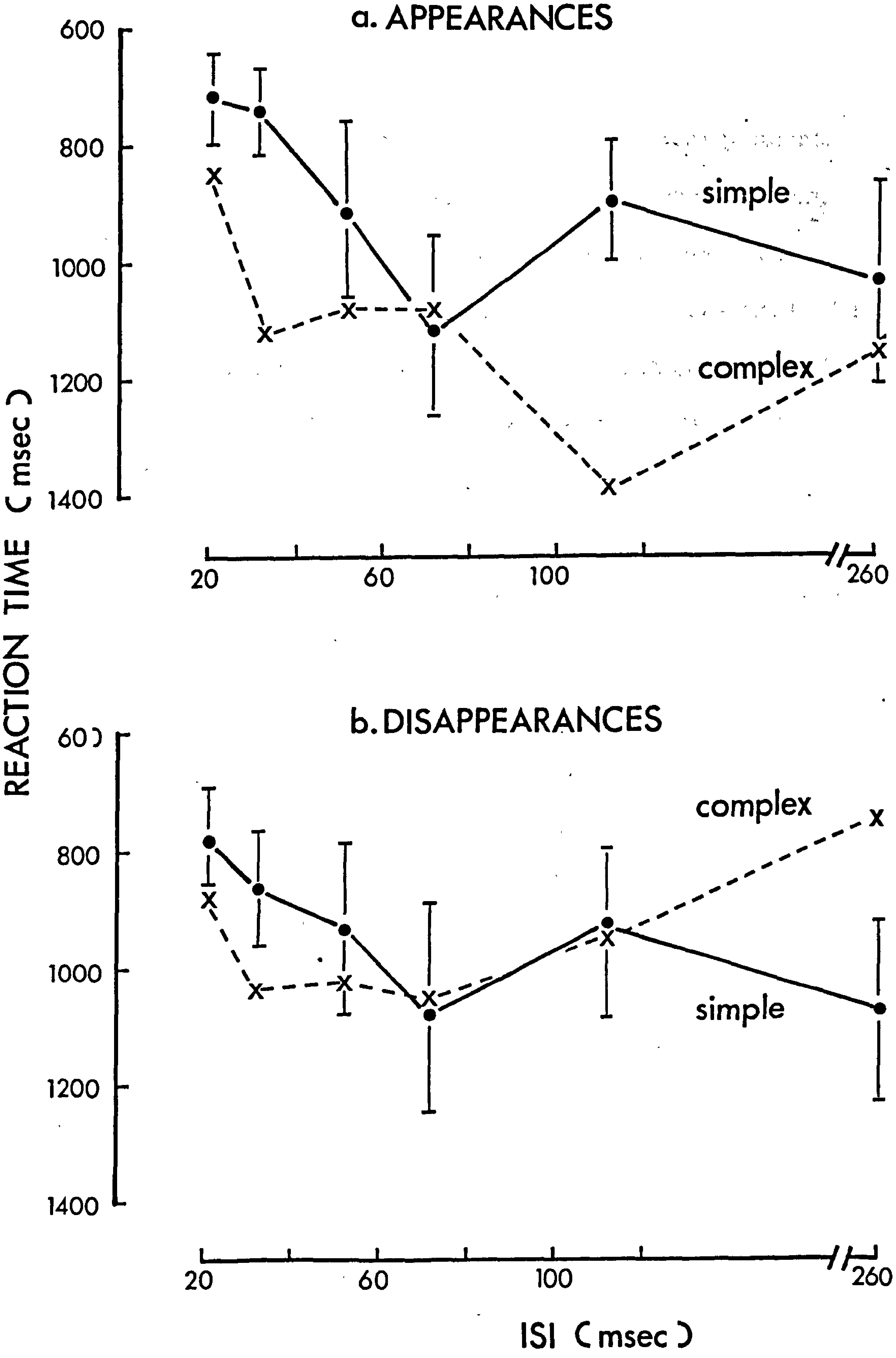

a. APPEARANCES
600
800
1000
1200
1400
simple
complex
20
60
100
260
REACTION TIME (msec)
b. DISAPPEARANCES
60)
800
1000
1200
1400
complex
simple
20
60
100
260
ISI (msec)

Fig. 2.7 [illegible] on p95

event detection task differs for simple and complex patterns. Nonetheless, given the differences between the two patterns, there is a marked similarity in the curves obtained. The results also indicate that the duration of sensory storage in the present experiment was very short: changes in complex patterns were detectable up to ISIs of only 32 msec. It will be convenient to discuss these two aspects of the results separately.

The curves obtained for simple and complex patterns are similar but nonetheless there are important differences between them. The question arises of whether these differences are attributable to an effect of complexity on sensory storage. Three differences between performance for simple and complex patterns will be considered.

Firstly, performance for complex patterns asymptotes at chance level while performance for simple patterns asymptotes well above chance. It is unlikely however that performance for simple patterns at longer ISIs reflects sensory storage: evidently the simple patterns are within the capacity of short-term visual memory (STVM) while complex patterns are not (Phillips, 1974). It should be noted that some decay is to be expected in STVM (Phillips, 1974). It is not clear whether such a decay is evidenced in the performance for simple patterns between ISIs of 52 and 260 msec in the present experiment.

Secondly, even at an ISI of 22 msec performance for simple patterns is considerably more accurate than performance for complex patterns. The level of performance achieved for complex patterns is sufficient to demonstrate that the storage underlying event detection is high capacity. However, the differences in performance for simple and complex patterns are considerably larger than the differences observed in Experiment I between corresponding patterns. This finding is embarrassing for the claim that the process and the storage underlying event detection are largely unaffected by pattern complexity. It is possible that the present finding is due to the slighly longer ISI used in this experiment: 22 msec as opposed to 20 msec in Experiment I. It is also possible that it is an artefact of the procedure employed in the present experiment. In both Experiment I and the present experiment it was difficult to persuade subjects that the task was possible with complex patterns. In the present experiment, however, the subjects' expectations appear to have been fulfilled: at only two of the six ISIs was performance for complex patterns above chance. The low overall level of performance attainable with complex patterns may thus have affected subjects' motivation when complex patterns were displayed.

Thirdly, performance for complex patterns shows a sharp fall as ISI is increased from 22 to 32 msec while performance for simple patterns does not. This could be interpreted as evidence that the onset of decay of storage was later for simple patterns than for complex patterns. However, it could also be due to a ceiling effect for performance with simple patterns. Such an effect would be consistent with the explanation of performance in the event detection paradigm offered by Phillips and Singer (1974; Singer and Phillips, 1974). Phillips and Singer, it will be remembered, propose that appearances and disappearances are detectable in so far as the activity they produce differs from that produced by interruptions. In the present experiment phenomenal reports indicated that at ISIs of 32 msec interruption was visible. On Phillips and Singer's model appearances and disappearances are detectable even when the ISI is long enough to give a visible interruption because the activity produced by interruption is partially suppressed by antagonistic inhibition. Phillips and Singer do not articulate the assumptions they make concerning the process which discriminates between the activity produced by appearance/disappearance and interruption. However, it seems reasonable to suppose that this process will be affected by the number of interrupted elements surrounding the event. Thus in the present experiment at ISIs of 32 msec it may have been comparatively easy to detect one event among 15 interruptions (simple patterns) but rather difficult to detect one event among 1023 interruptions (complex patterns). The differences in performance for simple and complex patterns at ISIs of 32 msec therefore need not be due to an effect of complexity on storage.

Thus although the effect of ISI on performance of an event detection task differs for simple complex patterns this need not reflect an effect of complexity on sensory storage.

The results of the experiment suggests that the duration of sensory storage is very short under present conditions of stimulation. This is particularly clear for complex patterns: performance for these patterns reached chance at ISIs of between 32 and 52 msec. In reviewing studies of sensory storage it was suggested that ISI does not give an unequivocal estimate of the duration of sensory storage in the event detection paradigm. Nonetheless this finding is in conflict with the view of the function of storage proposed by Phillips and Singer. The present finding is consistent with that reported by Lappin and Bell (1972) and suggests that changes which occur during interruptions can be detected only if the interruption is very brief. It thus seems unlikely that the event detection system is particularly designed to detect changes occurring during interruptions. There are a number of differences between the present conditions of stimulation and those employed by Phillips and Singer which could account for the discrepancy between the results. For example, the stimuli employed by Phillips and Singer were of a different colour and size and of a lower luminance than the stimuli in the present experiment. Furthermore subjects in Phillips and Singer's experiment appear to have been semi dark adapted. A pilot study was conducted on the effects of dark adaptation on performance in the present paradigm. The results suggested that the ISI over which changes could be detected in complex patterns increased to 52 msec when subjects were dark adapted.

2.4 General discussion of the experiments on event detection

The experiments on event detection had two main aims. Firstly, to investigate some of the limits of the ability to detect appearances and disappearances; it was hoped that such an investigation wold contribute to an understanding of the function of an event detection system. Secondly, to clarify the relationship between event detection and sensory storage.

2.4.1 Limits of event detection

The results of Experiments I and II show that a very high level of performance can be achieved in an event detection task under a wide variety of stimulus conditions. These experiments were largely unsuccessful in identifying limits to the ability to detect events, rather they demonstrate the extent of the ability. The findings of Experiments I and II are thus regarded as evidence that the ability to detect events is highly developed. This conclusion is reinforced by certain informal observations made during the course of the present experiments. The written description of the task given to subjects at the commencement of each session appeared to have little value for them. Typically subjects were completely bemused on the first trial of the practice. An understanding of the task seemed to arise around the second or third trial when the subject saw a change happen. Thus event detection is a complicated task which appears to be accomplished naturally.

The results of Experiment I indicate that events can be detected in complex and detailed stimuli. Furthermore Experiment II showed that varying the luminance of pattern elements over the maximum range practicable with the present display system has little or no effect on performance of an event detection task. In so far as similar conditions of stimulation are encountered in the natural visual environment the results of these experiments are regarded as evidence that the event detection system could operate efficiently in such an environment. Clearly, however, it should be remembered that a much greater range of conditions is found in the natural environment than is represented in these experiments.

Experiment III investigated the effect of varying ISI on the ability to detect changes in simple and complex patterns. The results indicated that a very brief interruption was sufficient to remove the highly accurate performance achievable in an event detection task. This was particularly clear for the detection of events in complex patterns: performance here asymptoted at chance level between ISI values of 32 and 53 msec. The ISIs over which appearances and disappearances were detectable under present conditions of stimulation are shorter than those reported by Phillips and Singer (1974). If this briefer period is more typical it would suggest that the event detection system is not particularly designed to detect changes occurring during interruptions.

The results of the present experiments are regarded as providing general support for the view that event detection is an important visual function. The experiments, however, give little information concerning the specific function or functions accomplished by the event detection system. The task in the present experiments required only detection of a difference between successive stimuli;it did not require this difference to be identified. Thus the present experiments do not indicate whether any information concerning an event is signalled other than that it has occurred. The experiments reported in the following Chapter therefore investigated whether event signals can be utilized for localization and pattern recognition.

Even if no information is signalled concerning events other than that they have taken place the event detection system could still perform the function of a general alerting mechanism. However, it should be noted that although the present experiments are not inconsistent with this hypothesis they do not give it any direct support. The display sequence in the present experiments was subject initiated. Thus it must be assumed that subjects were alert prior to the event taking place. The question of whether the event detection system can serve as an alerting mechanism merits further study. It would in fact be comparatively easy to modify the procedure in the event detection paradigm to investigate the detection of events under conditions of vigilance.

2.4.2 Event detection and sensory storage

The results of Experiments I and II are regarded as supporting a differentiation model of event detection. Differentiation theory predicts that a high level of performance will be achievable in an event detection task and that this performance will be largely unaffected by manipulation of the steady state properties of the stimulus array. Experiments I and II confirmed that highly accurate performance could be obtained in the event detection paradigm and that performance was largely unaffected by varying number of dots, size of array, separation between dots and by whether the luminance of the dots in the pattern was homogeneous or not. Furthermore the results of Experiment II are regarded as militating against an integration hypothesis. In so far as an integration theory implies that areas of change are identifiable by having an intermediate brightness it predicts that performance will be adversely affected by inhomogeneity in the luminance of surrounding areas. No evidence for such an effect was found in Experiment II. Thus the results of these experiments are regarded as evidence for a process or processes of differentiation in the visual system.

Although the results of Experiments I and II favour an explanation of event detection in terms of differentiation rather than integration neither experiment can be regarded as providing a crucial test of these explanations. Further evidence would clearly be required to establish the concept of differentiation. One way in which such evidence might be obtained is the following. It was noted earlier that the concept of enhancement of change was analogous to spatial contrast enhancement. If there are processes which enhance events then one would expect enhancement related illusions to occur with temporal illuminance distributions similar to those reported for spatial illuminance distributions. For example, it should be possible to produce a temporal analogue of the Cornsweet illusion (Cornsweet, 1970). Brindley (1970) reports that such an illusion is obtainable by varying the illuminance of a spatially uniform field over time in the same manner as the illuminance of the Cornsweet figure is varied in space. However, Brindley does not give any further details concerning the conditions under which this illusion was obtained. A pilot study was conducted which indicated that it was indeed quite easy to obtain a temporal analogue of the Cornsweet illusion. However, this and related phenomena have yet to be investigated systematically.

The high level of performance which could be obtained with patterns containing 1024 dots in Experiment I is evidence that the storage involved in event detection is very high capacity. Experiment III investigated the effect of ISI and pattern complexity on performance of an event detection task. The results of Experiment III confirmed that high capacity, short duration storage is involved in event detection. The effect of ISI differed for simple and complex patterns. However, it was argued that these differences could be attributed to factors other than an effect of complexity on storage. The results of Experiment III are thus regarded as confirming that sensory storage is involved in event detection. However, no attempt has been made to define the precise relationship between the storage evidenced by varying the ISI between patterns and the storage implicit in the concepts of integration and differentiation. The present experiments do not give enough information to allow this to be done. The physiological model proposed by Phillips and Singer suggests that the relationship between the sensory storage evidenced by varying ISI in the event detection paradigm and other forms of storage may in fact be rather complex.

CHAPTER 3: PERCEPTION OF PATTERNS OF EVENTS

The following experiments investigate the ability to perceive patterns of appearances and disappearances in random dot patterns. The rationale underlying the experiments on event perception is similar to that for the experiments on event detection. The two main aims of the following experiment were, firstly, to identify some of the limits of the ability to perceive patterns of events and, secondly, to investigate the relationship between event perception and sensory storage. The first experiment in the series, Experiment IV, investigates whether letters defined by configurations of appearances and disappearances can be identified. Experiment V, which is closely related to Experiment IV, attempts to measure the accuracy with which the relative position of events is specified. Experiment VI examines whether a process of integration similar to that hypothesized by Eriksen and Collins (1967; 1968) is evident in the event perception paradigm. Finally, Experiment VII investigates an apparent conflict between the present study and studies of visual integration.

3.1 Experiment IV: The recognition of letters defined by events

The aim of the present experiment was to establish whether patterns of events could be recognized. The preceding experiments have been concerned with the ability to detect events. The results of these experiments are regarded as indicating that the ability to detect events is highly developed. However, the event detection paradigm requires only that some difference between successive stimuli is detected it does not require identification of this difference. An event detection system may simply signal the fact that a change has occurred. On the other hand patterns of events may themselves convey information about form. The present experiment was therefore designed to investigate whether the latter was the case.

In addition to extending the investigation of the limits - or extent - of the ability to process events the present experiment also concerned sensory storage. It was noted in the Introduction that in so far as an event perception task was possible it would imply storage over and above that simply implied by event detection. That the ability to perceive patterns of events involves storage can be best demonstrated by considering the task employed in the present experiment. The subjects' task was to identify letters defined by configurations of appearances or disappeances in random dot patterns. Examples of dot patterns used as stimuli are shown in Figure 3.1. In this case, Figure 3.1 (a) followed by Figure 3.1 (b) would form the letter 'U' defined by disappearances. As can be verified the random dot patterns themselves give little

FIGURE 3.1

Experiment IV. Examples of the dot patterns used as stimuli: (a) a random dot pattern with an embedded target letter 'U'; (b) the same random dot pattern without the target letter 'U'. The patterns subtended $10^{\circ}45' \times 10^{\circ}45'$ when displayed. The patterns shown assume this size when viewed at a distance of approximately 40 cm.

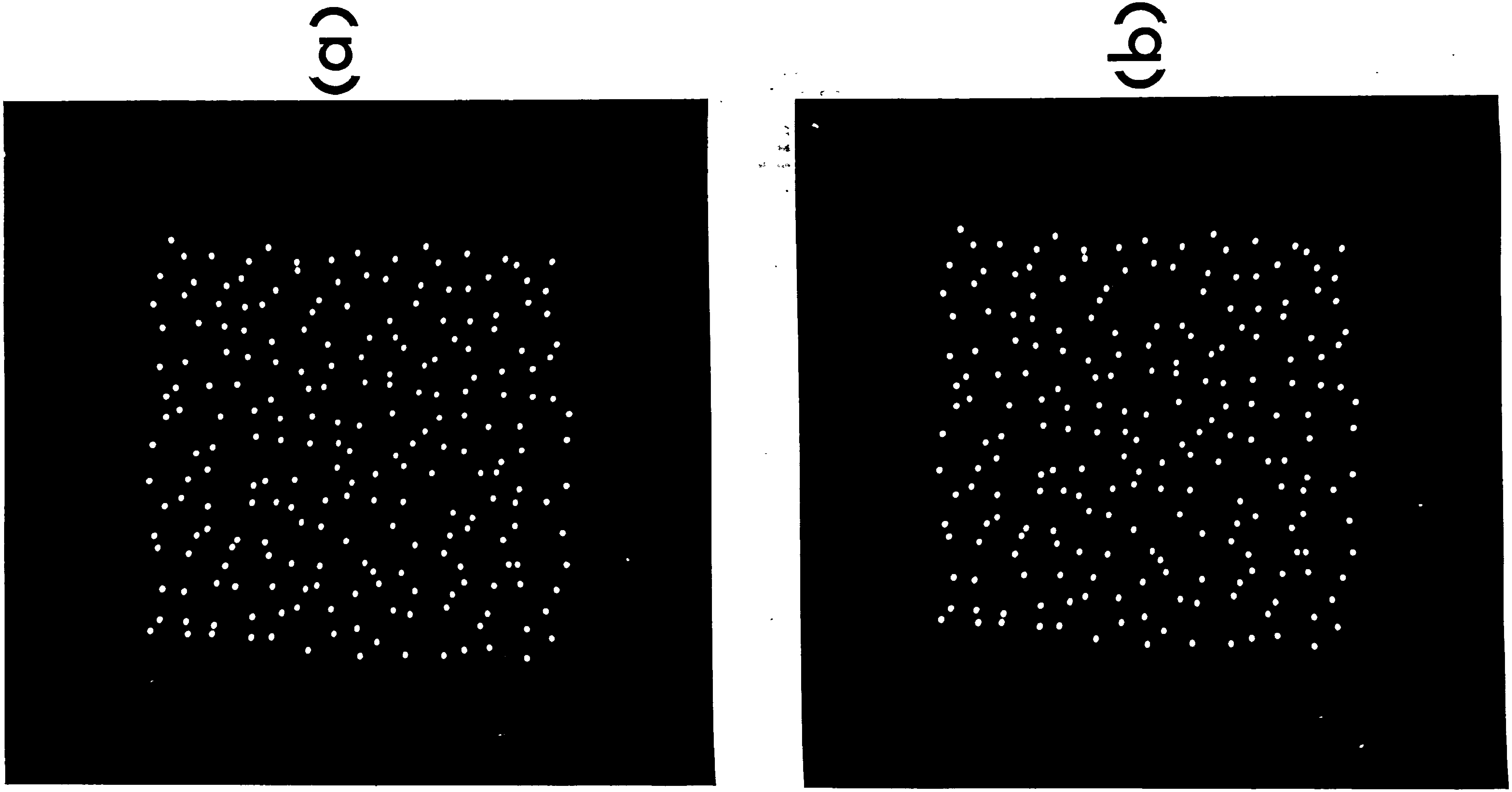


Fig 3.1 [illegible] [illegible] on P 108

or no information concerning the target letter. Under the conditions of the present experiment the appearance or disappearance of the target letter took place practically instantaneously. Thus if the letter is to be identified, the information that events have been detected at particular locations must be maintained for a time sufficient to allow this information to be utilized by perceptual processes. It should be noted that this argument is essentially a variant of the argument that sensory buffering is required because there is a change in rate/ capacity of processing in the visual system. The present experiment was therefore conducted to investigate whether such a task could in fact be performed. The succeeding discussion will consider two hypotheses concerning performance of such a task.

It is possible that event detection and pattern recognition systems are quite separate. This hypothesis is consistent with physiological evidence that cells in the visual pathway can be classified as either transient or sustained (Cleland, Dubin and Levick, 1971; Enroth-Cugell and Robson, 1966; Ikeda and Wright, 1974). It is often suggested that transient and sustained cells subserve the perception of change and form respectively (eg Tolhurst, 1973). If there is a sharp distinction between the functions of these two classes of cell then it is to be expected that events can not be used for the perception of form. However, there is evidence that the transient channel does give information concerning form (Kulikowski, 1975). Furthermore, as mentioned previously, Julesz (1971) and Lappin and Bell (1972) have demonstrated that forms defined only by differences between two successive patterns can be identified. Thus there is evidence that events can be used for form perception.

The second hypothesis concerning the relation between change detection and pattern recognition concentrates on the type of event involved. Eriksen and Collins (1967) suggest that discontinuity detection may inhibit pattern recognition processes. In particular they suggest such a role for the off response recorded at the level of the retina. Thus the proposal appears to be that the detection of a disappearance serves to terminate storage of information concerning form. Evidence for the discontinuity detection hypothesis has been provided by Holzworth and Doherty (1971). Subjects in Holzworth and Doherty's experiment viewed a briefly presented letter followed, after a variable interval, by the offset of a background field; at intervals of 60 msec or less a masking effect due to light offset was obtained. The discontinuity detection hypothesis receives further support from studies by Pollack (1973) and Hogben and di Lollo (1974). Extending the Eriksen and Collins argument it might be suggested that appearances serve to initiate pattern recognition processes. It might be expected, therefore that appearances can serve as the basis for pattern recognition while disappearances can not. This would account for the findings of Julesz (1971) and Lappin and Bell (1972). In these studies forms were defined by both appearances and disappearances. Thus form perception in the above experiments may have depended on the presence of appearances. In the present experiment the patterns were defined by either appearances or disappearances: thus the two types of event were studied separately.

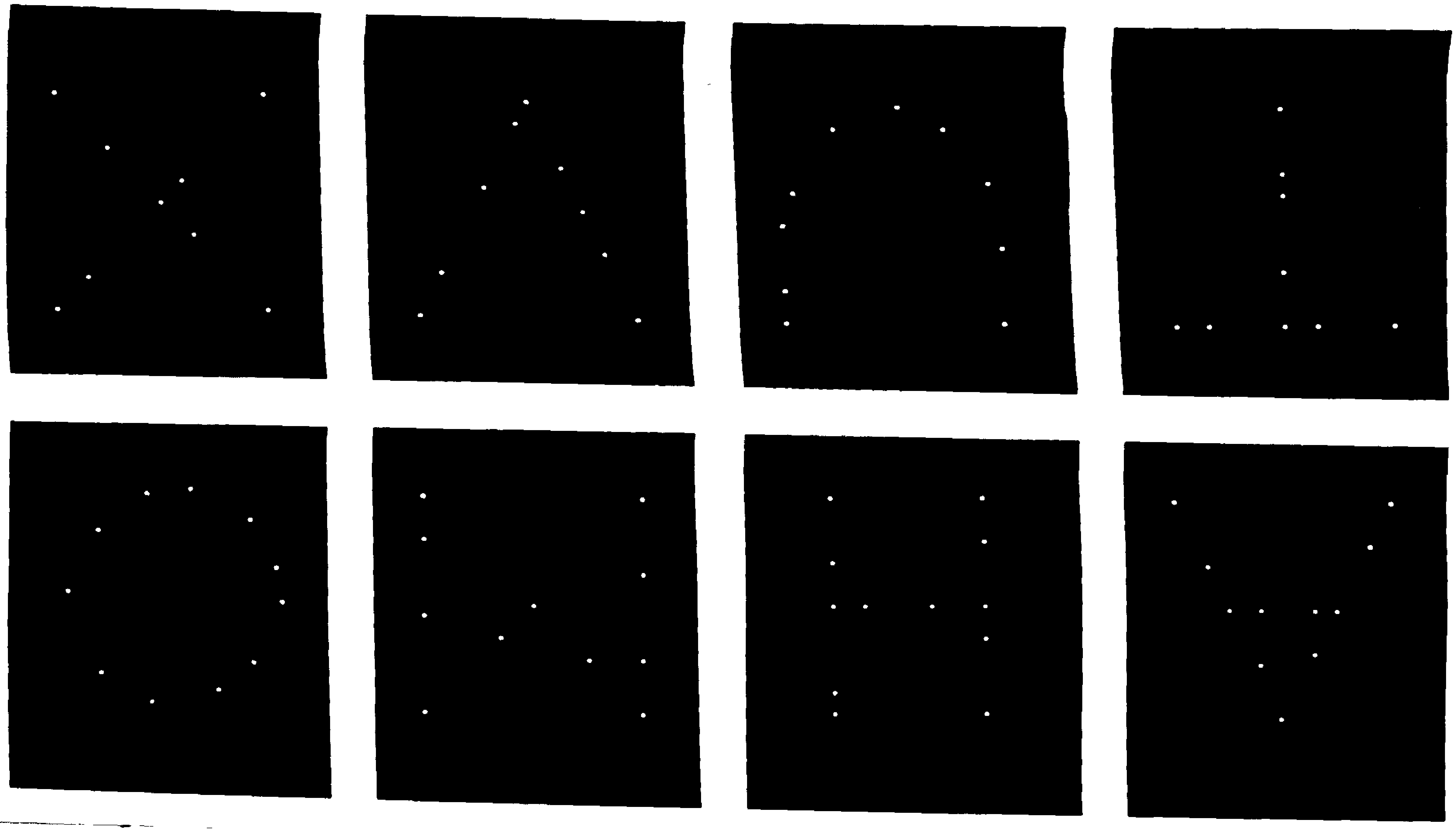
Method

Subjects: Subjects were 12 student- and staff volunteers from the Department of Psychology, University of Stirling. Subjects had normal or corrected to normal vision.

Stimuli: The eight symmetrical letters of the alphabet used as target stimuli are shown in Figure 3.2. The letters were A, H, M, O, T, U, V and X and were composed of between 9 and 12 dots plotted within $7^{o}13' \times 7^{o}13'$. The same configuration of dots was employed each time the letter was plotted. The letters could be embedded within and subtracted from random dot patterns. Examples of a random dot pattern with and without the letter 'U' are shown in Figure 3.1 (a) and (b) respectively. The random

FIGURE 3.2

Experiment IV. The eight letters of the alphabet used as target stimuli. Each letter was plotted within 7°13' x 7°13'. The letters shown assume this size when viewed at a distance of approximately 25 cm.



dot patterns were generated in the manner described in the General Methods section. A random dot pattern plus letter comprised 225 dots plotted within a $10^{0}45' \times 10^{0}45'$ square centrally located on the screen. A new random dot pattern was generated on each trial it was required.

There were four exposure conditions:

(1) Letter defined by appearances: a random dot pattern without an embedded letter followed by the same random dot pattern with an embedded letter. For example, Figure 3.1 (b) followed by Figure 3.1 (a) would form a 'U' defined by appearances. The durations of the first (t_1) and second (t_2) patterns were the same and equal to 480 msec, achieved by 25 refreshes each at 20 msec intervals. There was an ISI of 20msec.

(2) Letter defined by disappearances: a random dot pattern with an embedded letter followed by the same random dot pattern without an embedded letter. For example, Figure 3.1 (a) followed by Figure 3.1 (b) would form a 'U' defined by disappearances.
$t_1 = t_2 = 480$ msec, ISI = 20 msec.

(3) Letter alone: a target letter configuration displayed by itself. For example, the single letter 'U' from Figure 3.2. $t = 480$ msec.

(4) Embedded letter: a random dot pattern displayed with an embedded letter. For example, display of Figure 3.1 (a) would form the embedded letter 'U'. t = 480 msec.

The first two exposure conditions comprised the two types of event as used in previous experiments. The third and fourth conditions allowed base line data to be collected on the legibility of the letters and their detectability within random dot patterns.

Apparatus: The mask was removed from the GT40 keyboard and eight consecutive keys labelled with the eight letters used as stimuli.

Procedure: At the commencement of the experiment the subject read a printed sheet of instructions. The subject was asked to familiarize himself with the eight letters indicated on the keyboard. The subject was instructed to complete the task as quickly as possible but was told that correct responses were important and reaction time was not. The subject was instructed to ensure that his chin was on the chin rest and that he was fixating the displayed cross before initiating each trial. A trial consisted of the following sequence: The subject initiated the trial by pressing the space bar on the keyboard. The fixation cross was removed and followed by a blank interval of 100 msec. A letter was then displayed under one of the four exposure conditions. The subject's task was to indicate the letter presented on that trial by pressing the appropriate key on the keyboard. On each trial the subject had to select one of the eight letters indicated. The subject was instructed to guess if he was unsure which letter was presented. The machine indicated readiness for a new trial by re-displaying the fixation cross. The interval between the subject's response and the re-display of the fixation cross was approximately 2.5 seconds.

Subjects performed 16 trials under each of the four exposure conditions: two trials with each of the eight letters. The twelve subjects thus contributed a total of 192 observations per condition. Order of trials was determined by random selection without replacement from the total set of trials for that subject. There was a practice at the beginning of each session consisting of 8 trials under each condition. During the practice subjects were given knowledge of results.

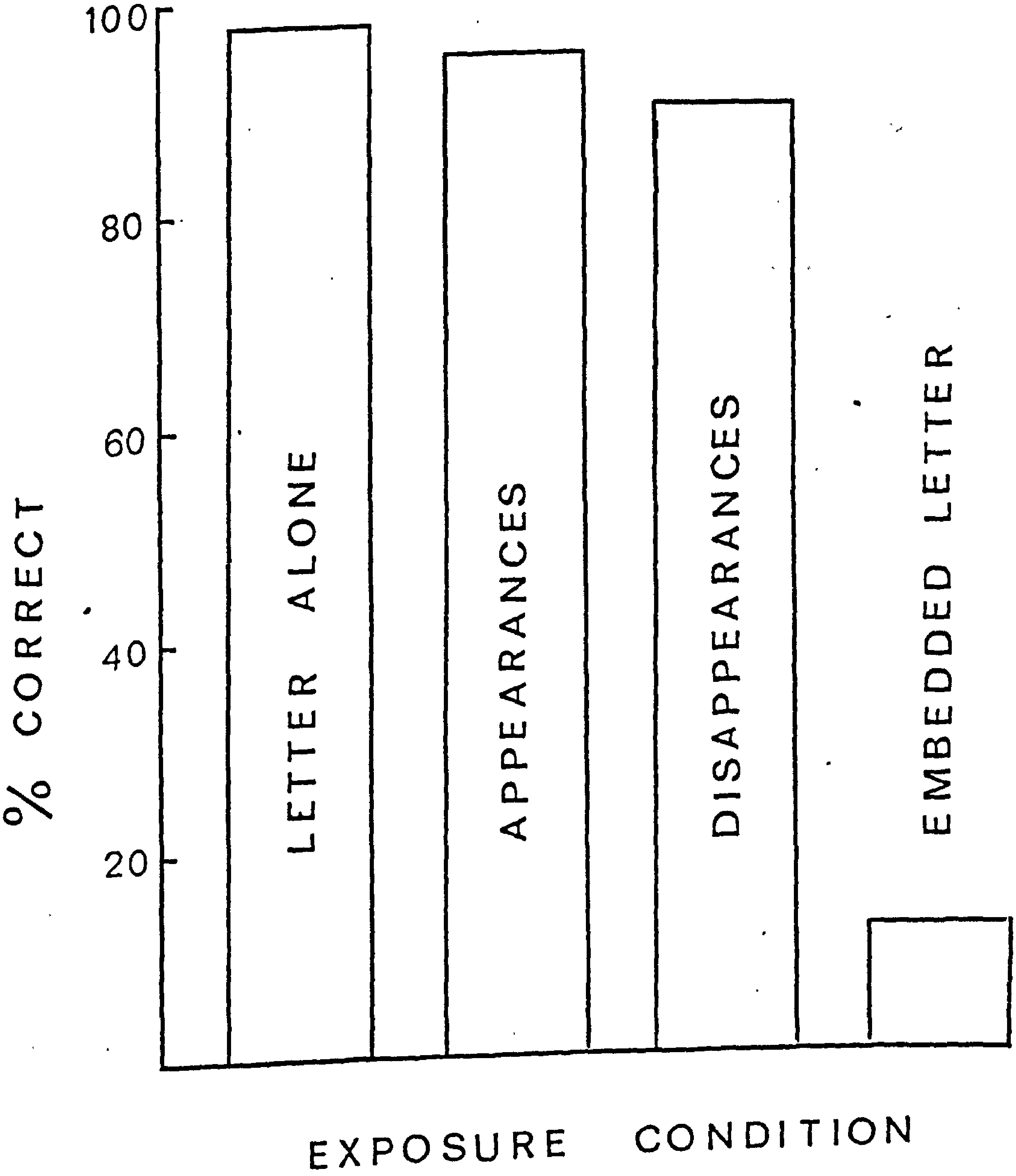
Results

The percentagesof correct response for each exposure condition are shown in Figure 3.3. Chance performance in this figure is 12.5% correct. A one-way repeated measures analysis of variance was performed on the number of correct responses. The analysis indicated that the effect of exposure condition was highly significant, $F(3.33) = 580.40$, $p < 0.001$. A follow up analysis indicated that performance under the embedded letter condition was significantly different from performance under all other conditions by the Scheffe Criterion ($\alpha = 0.05$). Under

FIGURE 3.3

Experiment IV. Percentages of correct response as a function of exposure condition. Chance performance is 12.5% correct.

Fig 3.3 opposite legend on p 116



this condition only 12% of responses were correct: thus the letters could not be detected when embedded in random dot patterns. Performance under all other conditions was accurate. Under the letter displayed alone condition 98% of responses were correct: thus the letters were quite legible. Performance of 95% correct for letters defined by appearances was not reliably different from performance for letters displayed alone. Performance of 90% correct for letters defined by disappearances was not reliably different from performance for appearances but was significantly different from performance for letters displayed alone ($\alpha = 0.05$). This performance is still well above chance.

Discussion

The results show that letters defined by patterns of appearances or disappearances can be recognised: 95% of letters defined by appearances and 90% of letters defined by disappearances were correctly identified. Thus both appearances and disappearances can serve as the basis for pattern recognition. The result for letters defined by disappearances has a paradoxical flavour: it implies that a pattern which is not visible is made visible by its disappearance. Performance of the present task is evidence for storage of information concerning events. Similar evidence that sensory storage is involved in event perception will be given by Experiment VI. Thus a consideration of this aspect of the present results will be postponed until the discussion of the following experiment.

The finding that patterns of events convey information concerning form suggests that one function of an event perception system may be the recognition of patterns of events. If change is of significance, it would clearly be advantageous to know not only that something has happened but also what has happened. The present results suggest that an initial identification of the form of change can be made on the basis of the event signals themselves. The present experiment required a finer discrimination of the relative visual position of events than the experiments of Julesz (1971) or Lappin and Bell (1972). However the letters employed in the present experiment were large in comparison to those, for example, in ordinary reading material. Thus it is not clear how accurately the location of events is specified. The results indicate that performance for letters defined by disappearances is poorer than performance for letters displayed alone. There is a further suggestion that performance for appearances may also be poorer than for letters displayed alone. The following experiment investigates whether there are differences in the accuracy with which the relative positions of appearances, disappearances and sustained stimuli are specified.

The results of the present experiment imply that the perception of pattern and change cannot be entirely separate functions. If change is signalled solely by transient cells then these cells must give information concerning the location of the change which is utilizable by pattern recognition processes. The results also argue against the idea that the detection of a disappearance terminates storage of information concerning form. Disappearances cannot serve to terminate pattern recognition processes simply because disappearances can themselves be used for the perception of form. The claim that disappearances per se do not inhibit perceptual processes does not rule out the possibility that events play a role in the temporal segregation of stimulation. The present results were obtained with events which were all of the same kind (i. e. either appearances or disappearances) and all occurring simultaneously. It is quite possible that departures from simultaneity or mixtures of different kinds of event inhibit the organization of a composite. The latter possibility is investigated in Experiment VII.

3. 2 Experiment V: The accuracy with which the relative position of detected events is specified

Experiment IV demonstrated that patterns of events could be identified, however it gave little indication of the limits of this ability. The ability to perceive patterns of events must depend, at least in part, on the accuracy with which the positions of the events are signalled. The aim of the following experiment, therefore, was to obtain a preliminary measure of the ability to localize events.

Pollack (1972 b) describes a method which might be used to investigate the ability to localize events. As previously mentioned, Pollack (1972 a) studied the ability to detect displaced dots within random dot patterns. Displacement was arranged by having a disappearance followed by an appearance in a different location. Pollack (1972 b) extended this study by requiring subjects to identify whether a specifically designated dot had been displaced. The displacement was followed, after an interval of 178 msec, by a probe circle which surrounded either the displaced dot or a nondisplaced dot: the subject's task was to indicate whether or not the queried dot had been displaced. By systematically varying the distance between the event and the probe it should be possible to measure the ability to locate an event in a random dot pattern. Unfortunately, although Pollack varied this distance he does not report the actual distances he used only the minimum distances. A pilot study was therefore conducted to discover whether the technique could be used to determine the ability to localize appearances and disappearances. Using Pollack's method it was found that, for both appearances, and disappearances, a distance of 1°10' between event and probe was necessary to achieve performance better than 75% correct. The suggestion was therefore that the acuity of the event signalling system was rather poor. During the pilot study, however, it was noticed that the event and the probe appeared to interact: when event and probe were at different locations there was apparent motion between them, when event and probe were at the same location the result depended on the type of event, appearances were apparently masked while disappearances produced an apparent interruption of the aftercoming circle. These interactions between event and probe altered the nature of the task: subjects were required to make inferences which they were not instructed to make. It was thus thought desirable to find an alternative method of measuring the acuity of the event signalling system.

The present experiment employed a variation of the alignment or vernier test. The target stimuli were three dots which were either in alignment or not in alignment and the subject's task was to indicate whether the dots were aligned or misaligned. Performance could thus be studied as a function of the lateral displacement of the central dot. This task was originally used by Ludvigh (1953). Ludvigh's stimulus was a row of three bright dots, each dot subtending 3". He found that the optimum separation of the outer, reference dots was 10 to 20 minutes of arc; at these separations a lateral displacement of approximately 2 seconds was sufficient to produce 75% correct judgements. The task can thus give a very fine measure of visual acuity. However, no attempt was made in the present experiment to measure the absolute acuity of event signalling. One reason for this was that the plotting accuracy of the display system used in the present experiments could not ensure perfect alignment of points. Nonetheless the task does allow an initial measure of the accuracy with which the relative position of detected events is specified.

Method

Subjects: Subjects were 16 Stirling University undergraduates with normal or corrected to normal vision.

Stimuli: The six types of target stimuli are shown in Figure 3.4. The target stimuli were three dots which could either be in alignment or not in alignment. When the dots were not in alignment the central dot was laterally displaced by one of five different distances: 5.8', 11.6', 23.2', 34.8' and 46.4'. The angular separation of the outer dots was $3^{o}37'$. For two reasons

FIGURE 3.4

Experiment V. Examples of the six types of target stimulus. The outer reference dots subtended 3°37' when displayed. The lateral displacements of the central dot were (1) 0° (2) 5.8' (3) 11.6' (4) 23.2' (5) 34.8' (6) 46.4'. The target stimuli shown assume these sizes when viewed at a distance of approximately 43 cm.

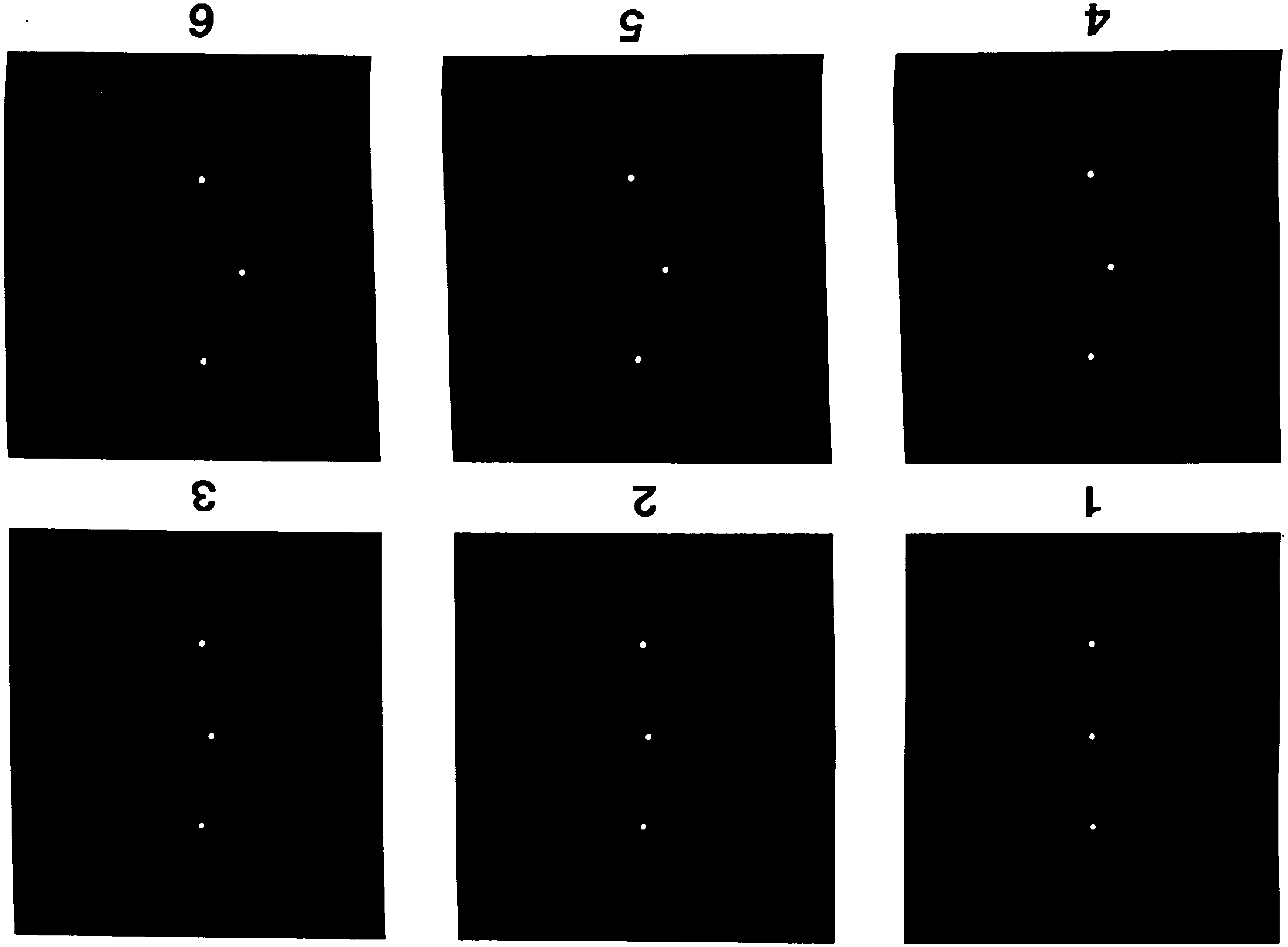


Fig 3.6 omnisite based on p 123

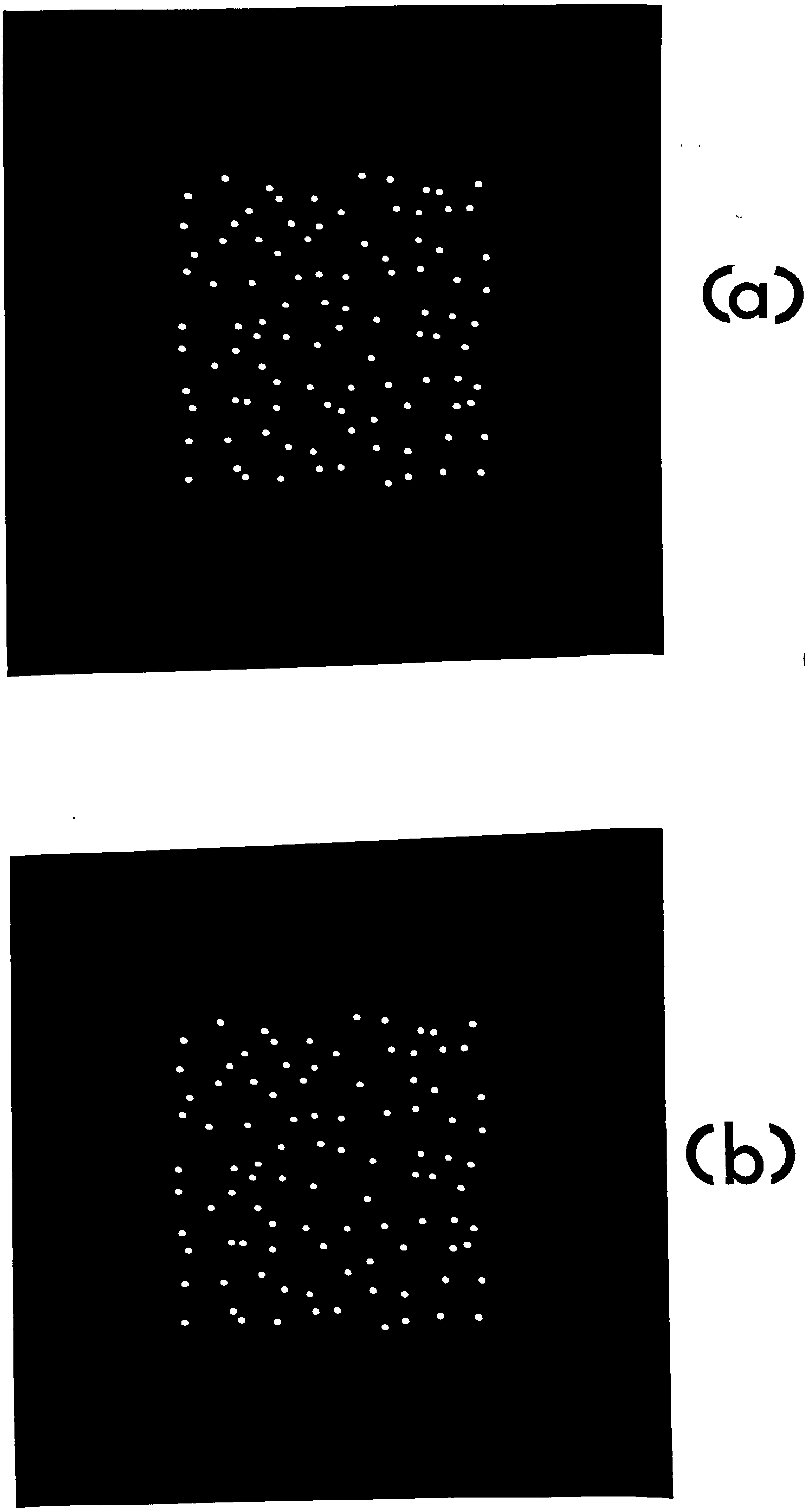
it was not possible to ensure perfect accuracy in the plotting of points. Firstly the display was composed of a raster of 1024 x 768 plottable points. Thus points could not be plotted continuously over the display surface. The maximum point plotting error from this source was ± 2'. Secondly, the GT40 display system has a limited plotting accuracy. The manufacturer specifies a dot repeatability of ± one dot diameter. Thus the maximum plotting error from this source was ± 4.8'. The errors from these sources were at times sufficient to produce a perceptible misalignment in points which should have been aligned.

The position and orientation of the target stimulus on the display surface were varied. The midpoint of the stimulus was located at random between + 43.5' and - 43.5' from the screen centre and the three dots were rotated about the screen centre to a randomly determined orientation of between 0^{o} and 359^{o}. The target stimulus configuration was thus plotted within a circle of diameter $3^{o}55'$ on screen centre.

As in Experiment IV target stimuli could be embedded within or subtracted from random dot patterns. Examples of a random dot pattern with and without a three - dot stimulus are shown in Figure 3.5 (a) and (b) respectively. The random dot pattern plus target comprised 100 dots plotted within a $7^{o}13' \times 7^{o}13'$ square centrally located on the screen.

FIGURE 3.5

Experiment V. Examples of the dot patterns used as stimuli: (a) a random dot pattern with an embedded 3 - dot target stimulus; (b) the same random dot pattern without the target stimulus. The patterns subtended $7^{\circ}13'$ when displayed. The patterns shown assume this size when viewed at a distance of approximately 40 cm.



Fi 2.5 [illegible] [illegible] 125

The three exposure conditions employed in this experiment were similar to the first three exposure conditions described for Experiment IV:

(1) Target defined by appearances. For example, Figure 3.5 (b) followed by Figure 3.5 (a). The durations of the first (t_1) and second (t_2) patterns were the same and equal to 495 msec, achieved by 100 refreshes each at 5 msec intervals. There was an ISI of 5 msec.

(2) Target defined by disappearances. For example, Figure 3.5 (a) followed by Figure 3.5 (b). $t_1 = t_2 =$ 495 msec. ISI = 5 msec.

(3) Target alone. For example, a single target stimulus from Figure 3.4. t = 495 msec.

Procedure: Subjects were given a printed sheet of instructions. The subject was informed that reaction time was being recorded but that accuracy was most important. The subject was instructed to ensure that his chin was on the chin rest and that he was fixating the displayed cross before initiating each trial. A trial consisted of the following sequence: The subject initiated the trial by pressing the right hand keyboard button. The fixation cross was removed and followed by a blank interval of 100 msec. A target was then displayed under one of the exposure conditions.

The subject's task was to indicate whether the target was in alignment or not by pressing buttons marked "bent" (left hand) or "straight" (right hand). On half the trials the target dots were in alignment and on half the trials they were not. The machine indicated readiness for a new trial by re-displaying the fixation cross. The interval between the subject's response and the re-display of the fixation cross was less than two seconds.

Each experimental session was divided into five separate blocks of trials. Subjects were tested with one of the five displacements in each block. A block consisted of 16 trials under each of the three exposure conditions: on eight trials the dots were aligned and on eight they were not. Order of trials within each block was determined by random selection without replacement from this set of 48 trials. At the start of each block of trials the subject was given 8 practice trials under each exposure condition with knowledge of results. Subjects were thus familiar with the particular discrimination to be tested during each block of trials. Order of displacements was randomized over subjects. The 16 subjects contributed a total of 256 observations per condition.

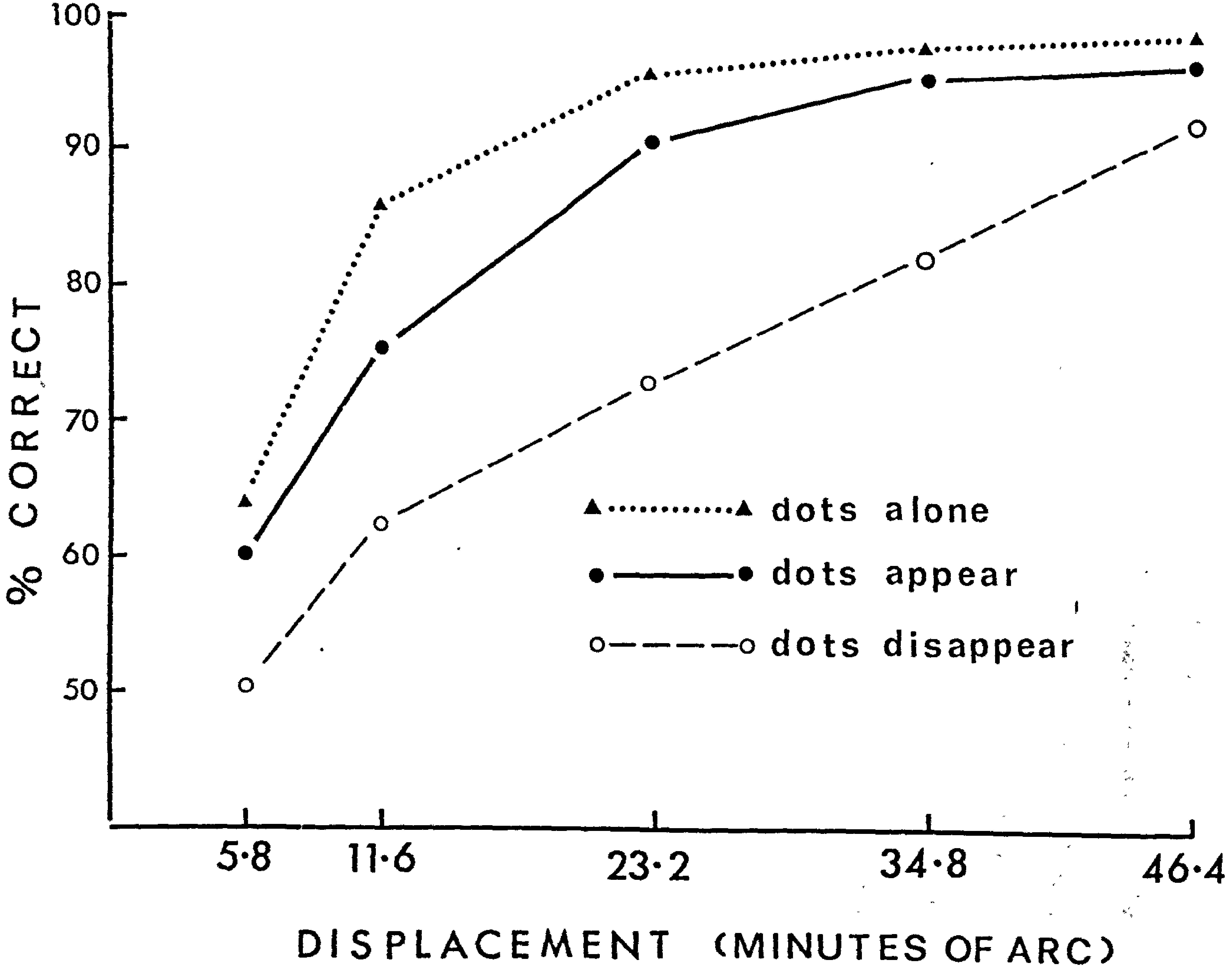
Results

Percentages of correct response are shown in Figure 3. 6 as a function of exposure condition and the displacement of the central dot. Chance performance in this figure is 50% correct. An analysis of variance was performed on the number of correct responses in accordance with a 3 x 5 x 16 (exposure condition x displacement x subjects) repeated measures design. There was a highly significant effect of displacement, $F(4, 60) = 113.11$, $p < 0.001$. As can be seen from Figure 3. 6 performance decreases as the displacement of the central dot decreases for all exposure conditions. There was also a highly significant effect of exposure condition, $F(2, 30) = 46.53$, $p < 0.001$. Planned comparisons (Hays, 1969) of overall performance under the three exposure conditions indicated that performance for a target defined by appearances was significantly poorer than for a target exposed alone, $t = 2.74$, $df = 30$, $p < 0.01$ (one-tailed), and that performance for a target defined by disappearances was significantly poorer than for a target defined by appearances, $t = 6.64$, $df = 30$ $p < 0.001$ (one-tailed). The analysis of variance also revealed a significant interaction between displacement and exposure condition, $F(8,120) = 2.59$, $p < 0.05$. Thus the effect of displacement depends on exposure condition.

FIGURE 3.6

Experiment V. Percentages of correct response as a function of exposure condition and the displacement of the central dot in minutes of an arc. Chance performance is 50% correct.

Fig 3-6 Omit legend on P.129



The accuracy with which the relative positions of target dots are specified under each exposure condition can be described in the following way: For targets defined by appearances a central dot displacement of 11.6 minutes was sufficient to produce 75% correct judgements; even with a central dot displacement of only 5.8 minutes judgements were 60% correct which is significantly better than chance (Z test, $\alpha = 0.05$). For targets defined by disappearances a displacement of 23.2 minutes gave 73% correct judgements, this level of performance does not differ significantly from the 75% threshold (Z test); performance was still better than chance with a central dot displacement of 11.6 minutes but did not differ significantly from chance with a displacement of 5.8 minutes (Z test). The analysis of variance indicates that performance for targets exposed alone was superior to performance for targets defined by events. However, performance for targets exposed alone shows a similar decrement with decreasing central dot displacement: with a displacement of 11.6 minutes judgements were 86% correct, with a displacement of 5.8 minutes 64% of judgements were correct, this level of performance is below the 75% threshold though still better than chance (Z test).

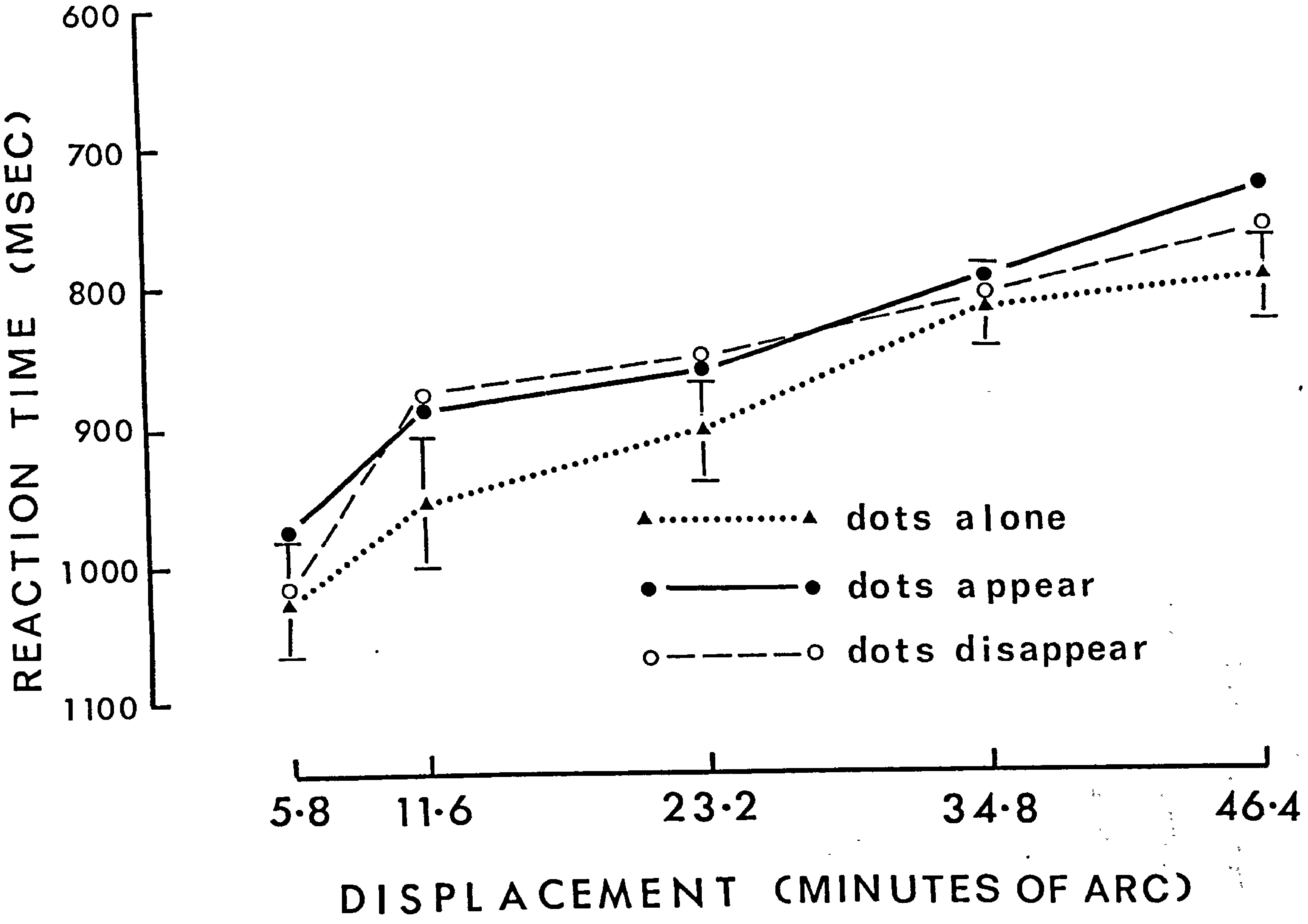
Mean reaction times of correct responses are shown in Figure 3.7 as a function of exposure condition and central dot displacement. The 0.05 confidence limits of the mean reaction times for targets exposed alone are indicated. As can be seen,

FIGURE 3.7

Experiment V. Mean reaction times of correct responses as a function of exposure condition and the displacement of the central dot in minutes of an arc. The 0.05 confidence intervals for the means of the dots exposed alone are indicated.

Fig 3.7

opposite legend on p 131



reaction times for targets defined by appearances and disappearances are very similar: the mean reaction times calculated over all displacements are 833 and 845 msec for appearances and disappearances respectively. However, there appears to be a trend towards longer reaction times for targets exposed alone than for targets defined by events: for targets exposed alone the mean reaction time calculated over all displacements is 896 msec.

Discussion

The experiment demonstrates that the alignment acuity of the event signalling system is measurable. No attempt, however, was made to measure the absolute acuity of the system. The results for targets exposed alone clearly indicate that present conditions of stimulation were sub-optimal: accuracy of performance for these targets was much poorer than that obtained by Ludvigh (1953) using a similar task. There are a number of ways in which present conditions of stimulation may have been less than optimal. The inaccuracy of the display system has already been mentioned. Additional factors may have included the relatively large separation between reference dots, the size of dots, dot contrast etc. Furthermore it should be remembered that the present results reflect the average performance of a sample of subjects rather than the performance attainable by individual S's. Although no large differences in the abilities of S's were observed in the present experiment, further study would be required to establish the precise extent of individual differences.

Although the present results do not allow conclusions to be drawn concerning the absolute acuity of the event signalling system they do indicate the minimum specificity of event signalling. That is, the acuity of the event signalling system must in general be at least as good as that indicated by present results. The results show that the relative positions of events are not specified as accurately as the positions of dots exposed alone. Thus it would seem that the event signal cannot be used for finer pattern recognition processes. Nonetheless the results suggest that the positions of events are specified accurately enough to allow them to drive selective processes, for example, foveating eye movements. Thus although the event signal itself does not appear to allow detailed pattern recognition it could function to direct such processes to areas of change.

The results of this and the previous experiment are regarded as implying that information concerning events is stored. The evidence for this conclusion is essentially that it is possible to perform tasks requiring either recognition of letters defined by patterns of events or localization of the relative positions of three events. That these tasks required storage is clearest for targets defined by disappearances. It was shown in Experiment IV that identification of target letters embedded in random dot patterns was at chance level. Thus under present conditions of stimulation the pattern displayed before the target disappears gives little or no information concerning the target, while the disappearance itself occurs practically instantaneously. However, it must be assumed that the perceptual processes necessary for performance of recognition or localization tasks cannot be accomplished instantaneously. Thus performance of such tasks implies that information is stored concerning the disappearance of the target. That storage is involved in the perception of targets defined by disappearances is more obvious than that it is involved in the perception of targets defined by appearances. This is simply because the target is not physically present after disappearance but is present after appearance. It might in fact seem paradoxical to suggest that storage is necessary for utilization of information concerning a target which is physically present. However, for targets defined by appearances, it is the fact that target dots have appeared which distinguishes them from non-target dots; information concerning the appearance of the target must therefore be stored. It has already been suggested that one function of an event signalling system may be to direct selective processes to areas of change. Since the target is physically present after appearance it is possible that the target is marked by such processes. On this view the ability to utilize information concerning the target would reflect the operation of selective processes rather than sensory storage. However, two considerations argue against this view. Firstly, selective processes must themselves be assumed to require time to be activated. Secondly, there was a strong phenomenal impression that targets defined by appearances were available for only a limited period: the presence of the target was obvious immediately after the events occurred but target dots quickly became indistinguishable from non-target dots, although it was possible to fixate or attend to single points. Thus although the level of performance in recognition and localization tasks achieved for targets defined by appearances may partly reflect the operation of selective processes, the ability to perform the task at all appears to imply some form of storage. Thus the present results are regarded as evidence that the event signal conveys information concerning the location of the event and furthermore that this signal is sufficiently extended in time to be utilized by perceptual processes.

The results of the present experiment confirm the differences suggested by Experiment IV between performance for targets presented alone and defined by appearances and disappearances. Specifically, the present experiment shows that performance of a localization task is better for targets alone than for targets defined by appearances which in turn is better than for targets defined by disappearances. On the basis of the preceeding discussion a number of possible explanations of these differences could be advanced. For example, the differences could be due to the duration or quality of the representation which is available under each presentation condition. Alternatively or additionally the superiority of performance for appearances over performance for disappearances could reflect the operation of selective processes in the case of appearances which are redundant for disappearances. The results of the present experiment do not allow discrimination between these hypotheses. Nonetheless two possible explanations for these differences do appear to be ruled out on the basis of the present study. Firstly, it might be argued that the differences in performance under the three exposure conditions are due to differences in the detectability of the target. However, the results of Experiment I suggest that there should be very few failures to detect events in the patterns used in the present experiment and that any differences in the detectability of appearances and disappearances should be very small. Furthermore, any differences in the detectability of the target under the three exposure conditions should be constant and unaffected by the displacement of the central dot. However, the results of the experiment indicate that there was a significant interaction between exposure condition and displacement: thus the differences between exposure conditions varied with displacement. Thus, although there may be a small contribution from differences in detectability it seems probable that the observed differences reflect genuine differences in the ability to localize the relative positions of target dots under the three exposure conditions. Secondly, the difference between performance for appearances and disappearances might be attributed to a difference in the resolution of the channels responsible for coding light onset and light offset. However, the results of a pilot study argue against this hypothesis. The pilot study employed substantially the same procedure as was used in the present experiment. However, stimuli were tachistoscopically presented and were composed of black dots inked on white card. The results of this study indicated superior performance for appearances of a three-dot target over performance for disappearance of a target. Thus whether dots are light or dark appears to be irrelevant to obtaining superior performance for appearances. It thus seems unlikely that the differences between appearances and disappearances observed in the present study are due to an asymmetry between on - and off - centre cells.

3.3 Experiment VI: The effect of the durations of first and second patterns on the perception of events.

The results of Experiment IV show that letters which are defined by the difference between two successive patterns can be identified. This experiment serves to emphasize the similarity of the event perception paradigm and the Eriksen and Collins paradigm: in both paradigms a task is performed which requires utilization of information from two successive stimuli. The similarity of the paradigms has already been alluded to in the Introduction. It was noted that Eriksen and Collins (1967; 1968) suggest that performance of their task and the variables affecting performance can be understood in terms of persistence and integration. It was further suggested that performance of event detection and perception tasks could also be explained in terms of such concepts. However, the results of Experiments I and II are regarded as evidence that event detection in fact depends on an additional process of differentiation. The similarity between the Eriksen and Collins paradigm and the event perception paradigm suggests a way in which evidence for an integration explanation of performance in the present paradigm might be obtained. If performance of an event perception task is affected in a similar manner by the same variables as performance in the Eriksen and Collins paradigm then an integration model of event perception would be favoured. A convenient starting point for a comparison between the paradigms lies in the effect of the exposure durations of the first and second patterns when the ISI between patterns is zero or very short.

The original demonstration of storage by Eriksen and Collins (1967) employed exposure durations of the two stimulus halves which were the same and equal to 6 msec. Thus the initial evidence for persistence and integration given by Eriksen and Collins was obtained with durations of the first (t_1) and second (t_2) patterns very much shorter than those employed in present experiments. There is evidence that performance in the Eriksen and Collins paradigm decreases as t_1 and t_2 increase. Cohene (1975) reports that, with a zero ISI between patterns, accuracy of performance of the Eriksen and Collins task decreased as the exposure durations of equal duration halves increased from 25 to 75 msec. A similar result is reported by Pollack (1973). Neither Cohene nor Pollack report the presentation durations at which performance asymptotes under their conditions of stimulation, however, their data imply that such an asymptote would be reached at exposure durations shorter than those employed in the present experiments. It appears therefore that the processes of persistence and integration evident in the Eriksen and Collins paradigm at short durations of t_1 and t_2 are not evident at longer stimulus durations. The present experiments indicate that, under appropriate conditions, maximal performance of event detection and perception tasks can be obtained at long stimulus durations. It thus seems unlikely that the processes delineated by Eriksen and Collins can account for performance of these tasks at long presentation durations. Nonetheless, it is possible that event perception based on the integrative processes proposed by Eriksen and Collins is evident at short stimulus durations. The aim of the present experiment was to investigate whether this was the case.

Central to the Eriksen and Collins' concept of integration is the notion that "inequality in energy between stimulus halves reduces integration or organization of the imbedded nonsense syllable" (Eriksen and Collins, 1967 p. 482). Eriksen and Collins present evidence that such an effect of inequality occurs when energy is manipulated by varying either stimulus luminance (Eriksen and Collins, 1968) or stimulus duration (Eriksen and Collins, 1967). The latter study is of particular interest here. Eriksen and Collins (1967) investigated the effect of mismatch in the durations of the two stimulus halves and order of occurrence of short and long halves. They employed three ISIs: concurrent, 0 and 20 msec. The duration of the short half was always 25 msec. They found that performance decreased as long half duration increased over the range 25 to 150 msec. They also found that performance was unaffected by order of occurence of the two stimulus halves except when they were displayed concurrently. Eriksen and Collins regard their results as being consistent with their concept of integration, although they note that the general lack of an effect of order of occurrence argues against a simple decay explanation. Pollack (1973) has confirmed an effect of inequality in stimulus halve durations on performance of an integration task. Pollack's results suggest that this effect is separate from any overall decrement in performance with increasing stimulus durations.

The hypothesis for the present experiment was that the integrative processes delineated by Eriksen and Collins would be evident in the event perception paradigm at short durations of t_1 and t_2 and would allow performance of an event perception task. This hypothesis implies two predictions: firstly, that it will be possible to perform an event perception task at short durations of t_1 and t_2 and, secondly, that performance will be adversely affected by inequalities in the durations of t_1 and t_2. The subjects' task in the present experiment was similar to that of Experiment V: to indicate whether three events were in alignment or not. Performance of this task was investigated as t_1 and t_2 were varied over the range 15 to 155 msec in a factorial design.

Method

Subjects: Subjects were 18 Stirling University undergraduates with normal or corrected to normal vision. Participation fulfilled a course requirement.

Stimuli: The stimuli used in this experiment were similar to those used in Experiment V. Target stimuli were three dots which could be either in alignment or not in alignment. When the dots were not in alignment the lateral displacement of the central dot was 43.5'. The outer, reference dots subtended $3^{o}57'$. The experiment employed eight target stimuli with predefined orientations and positions. The stimuli had four orientations: 0^{o}, 48^{o}, 90^{o} and 144^{o}. The distances from the centre of the screen to the midpoints of target stimuli at these orientations were 32', 29', 16' and 16' respectively. At each orientation/position the dots could be either in alignment or not in alignment. When the dots were not in alignment the central dot was laterally displaced towards the screen centre. The central dots were thus plotted within a circle of diameter $1^{o}4'$ on screen centre and the outer dots were plotted within a circle of diameter 4^{o}.

As in previous experiments the target stimuli could be embedded within or subtracted from random dot patterns. The type of dot pattern used in this experiment was similar to that employed in Experiment V: 100 dots plotted within a $7^{o}13' \times 7^{o}13'$ square.

The target was defined by two types of event:

(1) Target defined by appearances: a random dot pattern without a target followed by the same random dot pattern with a target.

(2) Target defined by disappearances: a random dot pattern with a target followed by the same random dot pattern without a target.

These two conditions correspond to the first two exposure conditions employed in Experiment V.

The durations of the first (t_1) and second (t_2) patterns of the sequence were manipulated by varying the number of successive refreshes accorded to each pattern. Four different numbers of refreshes were employed: 4, 8, 16 and 32. As in Experiment V these refreshes were at 5 msec intervals, thus these numbers of refreshes gave exposure durations of 15, 35, 75 and 155 msec respectively. A lower limit of 4 refreshes were chosen because it was the shortest duration at which patterns were still clearly visible. A factorial combination of four t_1 durations and four t_2 durations gave a total of 16 t_1 x t_2 combinations. There was an ISI between patterns of 5 msec.

<u>Procedure</u>: Subjects were instructed that reaction time was being recorded but that accuracy was most important. The subject was instructed to ensure that his chin was on the chin rest and that he was fixating the displayed cross before initiating each trial. The procedure for each trial was identical to that described for Experiment V. The subject's task was again to indicate whether the target dots were in alignment by pressing the appropriate

button on the keyboard.

The two types of event by four t_1 durations by four t_2 durations yielded a total of 32 conditions. Subjects performed 8 trials under each of these conditions: one trial with each of the 8 target stimulus configurations. The 18 subjects thus contributed a total of 144 observations per condition. Order of trials was determined by random selection without replacement from the total set of trials for that subject. There was a practice for each subject at the beginning of the session consisting of two trials under each condition. During the practice the machine indicated correct and incorrect responses.

Results

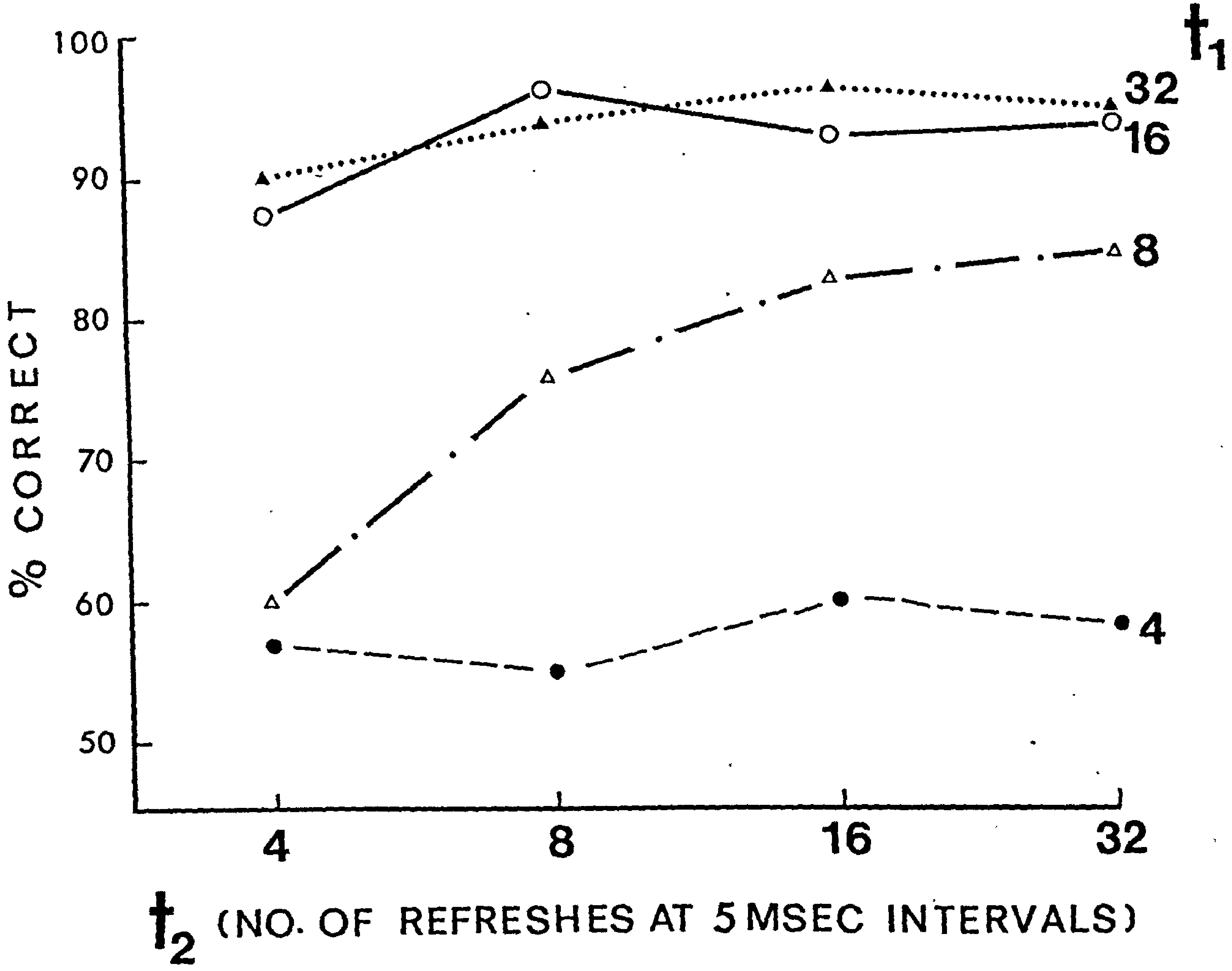
Percentages of correct response are shown in Figure 3.8 for (a) appearances and (b) disappearances as a function of t_1 and t_2 in 5 msec intervals. Note that for appearances t_1 is plotted on the abscissa and t_2 is plotted as a parameter while for disappearances t_2 is plotted on the abscissa and t_1 is plotted as a parameter; the reasons for this inversion will be made clear below. Chance performance in this figure is 50% correct.

A repeated measures analysis of variance was performed on the number of correct responses. The analysis followed the design of the experiment: two types of event by four t_1 durations by four t_2 durations by 18 subjects. The analysis revealed a

FIGURE 3.8 (a)

Experiment VI. Target defined by appearances. Percentages of correct response as a function of t_1 and t_2 in number of refreshes at 5 msec intervals; t_1 is plotted on the abscissa and t_2 is plotted as a a parameter. Chance performance is 50% correct.

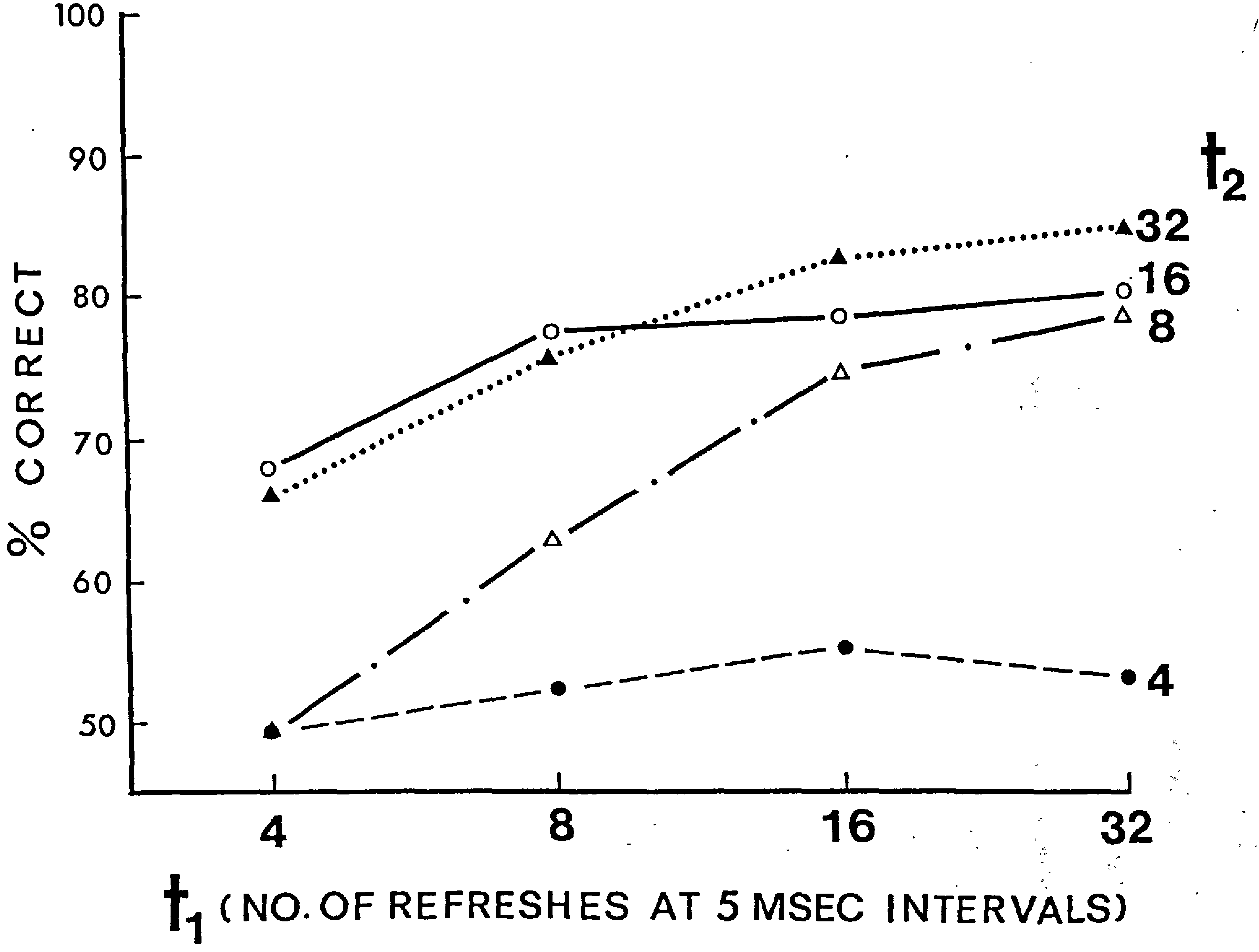
Fig 3-8 (a) opposite legend on p.145



(a) APPEARANCES

FIGURE 3.8 (b)

Experiment VI. Target defined by disappearances. Percentages of correct response as a function of t_1 and t_2 in number of refreshes at 5 msec intervals; t_2 is plotted on the abscissa and t_1 is plotted as a parameter. Chance performance is 50% correct.



(b) DISAPPEARANCES

Fig 3.8 (b) opposite legend on p 146

significant difference between performance for appearances and performance for disappearances, $F(1,17) = 57.59$, $p < 0.001$. Overall performance for appearances was superior to that for disappearances. There were also significant effects of t_1, $F(3,51) = 80.60$, $p < 0.001$, and t_2, $F(3,51) = 24.28$, $p < 0.001$. For both appearances and disappearances performance increased as a function of increases in t_1 and t_2, however the presence of a series of interaction effects indicates that the form of this relationship is rather complex. There was a significant interaction between t_1 and t_2, $F(9,153) = 3.10$, $p < 0.01$. Thus the effects of t_1 and t_2 were interdependent. There were also highly significant interactions between type of event and t_1, $F(3,51) = 16.62$, $p < 0.001$ and type of event and t_2, $F(3,51) = 7.01$, $p < 0.001$. Thus the effects of t_1 and t_2 differ for appearances and disappearances. Although the analysis indicates the presence of complex effects, the obtained interactions do not appear to reflect a detrimental effect on performance of inequality in the durations of t_1 and t_2. For equal t_1 and t_2 an increase in either t_1 or t_2 either improved performance or had little or no effect on it, while a decrease in t_1 or t_2 either decreased performance or had little or no effect on it. An increase in performance with increases in t_1 or t_2 is not consistent with an inequality effect. A decrease in performance with decreases in t_1 and t_2 is consistent with an inequality effect, however the overall pattern of results suggests that such decreases in performance reflect a general tendency for performance to decrease with decreasing presentation duration rather than an effect of inequality in stimulus durations. In this context it should also be noted that although performance for targets defined by appearances at equal t_1 and t_2 durations of 4 refreshes is signficantly better than chance (Z test, $\alpha = 0.05$), performance for targets defined by disappearances at the same durations of t_1 and t_2 was not.

An examination of the data suggested that the interactions between type of event and presentation duration relfected a symmetry in the effects of t_1 and t_2 on the perception of appearances and disappearances. In Figure 3.8 the data are plotted in a manner which illustrates the extent of this symmetry. As can be seen from Figure 3.8 (a) and (b) there is a marked similarity in the graphs for appearances and disappearances when t_1 and t_2 are interchanged as abscissa and parameter. The data were therefore re-analysed interchanging t_1 and t_2 over appearances and disappearances. All main effects were again significant beyond the 0.001 level. There was a significant interaction between exposure durations, $F(9,153) = 4.48$, $p < 0.001$. However, the interactions between exposure durations and type of event were attenuated. The interaction between type of event and the factor representing t_1 for appearances and t_2 for disappearances was significant, $F(3, 51) = 4.04$, $p < 0.05$, while the interaction between type of event and the factor representing t_2 for appearances and t_1 for disappearances was not, $F(3, 51) = 1.67$, $p < 0.05$.

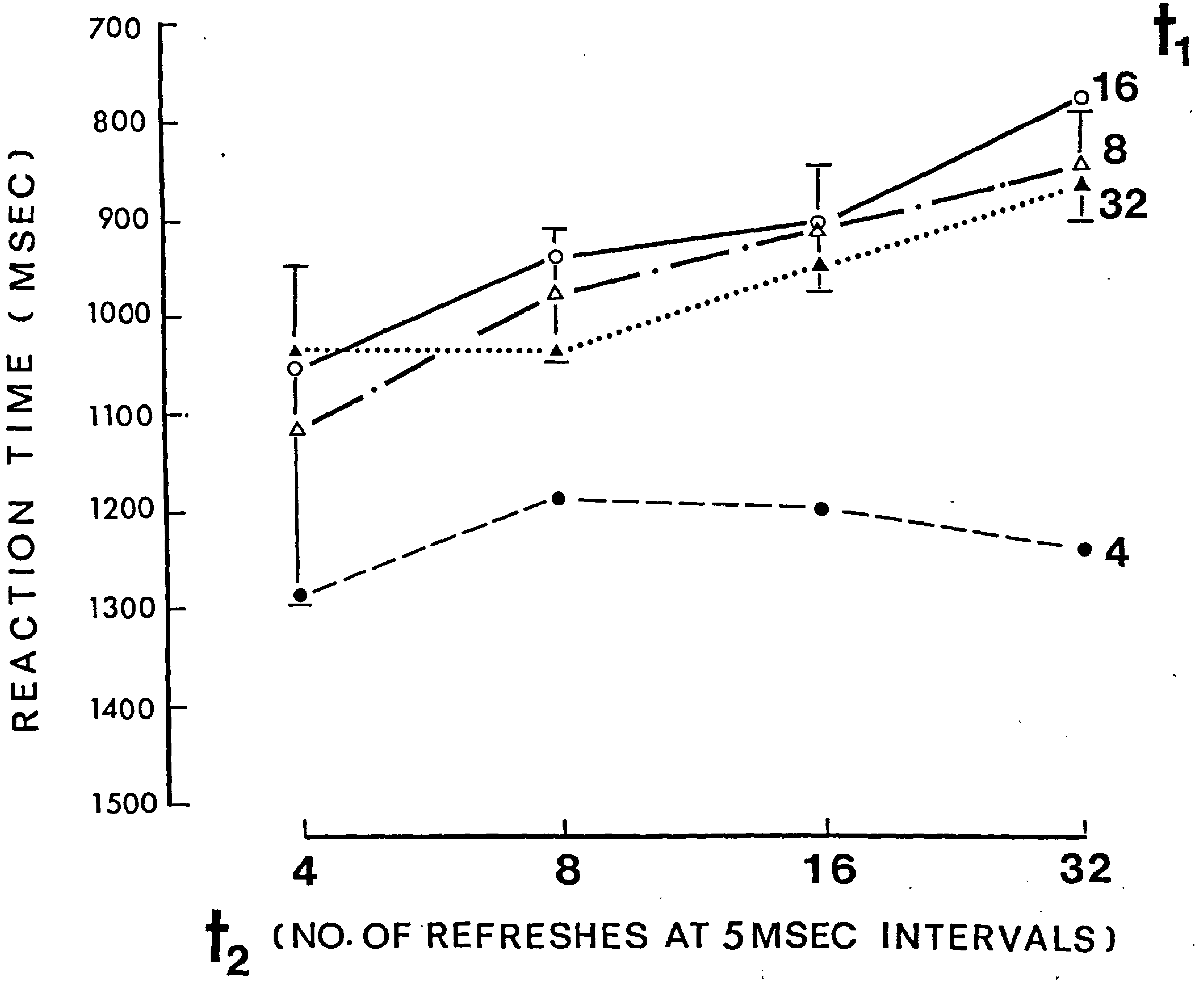
Thus the effects of t_1 and t_2 on the perception of appearances and disappearances are symmetrical though not precisely so. The data shown in Figure 3.8 (a) and (b) can be described in the following way: Performance for appearances (disappearances) increased as t_1 (t_2) is increased from 4 to 16 refreshes; increasing t_1 (t_2) from 16 to 32 refreshes appears to have had little or not effect on performance. It should be noted, however, that for disappearances a ceiling to performance appears to have been reached by a t_1 of 8 refreshes for longer durations of t_2. Performance for appearances (disappearances) showed a marked increase with increases in t_2 (t_1) in the range 4 to 32 refreshes only when t_1 (t_2) equalled 8 refreshes; at other durations of t_1 (t_2) effects of t_2 (t_1) are much less marked.

Mean reaction times of correct responses are shown in Figure 3.9 for (a) appearances and (b) disappearances as a function of t_1 and t_2 in number of refreshes at 5 msec intervals. The positions of t_1 and t_2 are interchanged in a manner similar to that for Figure 3.8. The results for reaction times indicate

FIGURE 3.9 (a)

Experiment VI. Target defined by appearances. Mean reaction times of correct responses as a function of t_1 and t_2 in number of refreshes at 5 msec intervals; t_1 is plotted on the abscissa and t_2 is plotted as a parameter. The 0.05 confidence limits of the means for $t_1 = 8$ refreshes are indicated.

Fig 3.9 (a) opposite legend on p 150



(a) APPEARANCES

FIGURE 3.9 (b)

Experiment VI. Target defined by disappearances. Mean reaction times of correct responses as a function of t_2 and t_1 in number of refreshes at 5 msec intervals; t_2 is plotted on the abscissa and t_1 is plotted as a parameter. The 0.05 confidence limits of the means for $t_2 = 8$ refreshes are indicated.

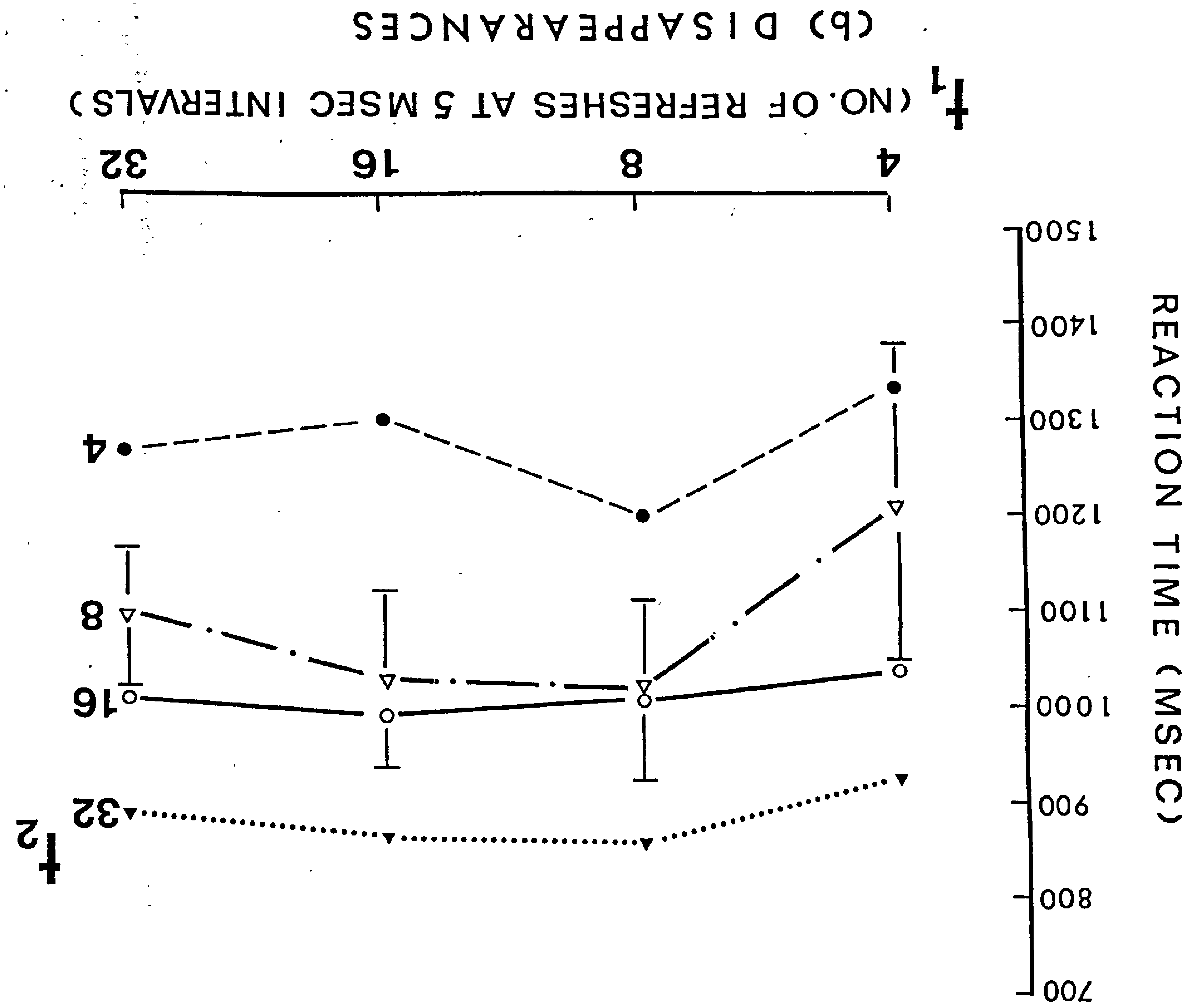


Fig 3.9 (b) opposite legend on p 151

that the symmetry evident in the number of correct responses is not paralleled by a symmetry in the reaction time data.

Discussion

The results of the experiment do not support the hypothesis that event perception based on the integrative processes delineated by Eriksen and Collins is evident at short durations of t_1 and t_2 in the present paradigm. At the shortest durations of t_1 and t_2 used in the experiment ($t_1 = t_2 = 4$ refreshes) performance was above chance for appearances but not for disappearances. Thus for targets defined by disappearances the task was not possible at short durations of t_1 and t_2. More importantly, there is little evidence for an adverse effect on performance of inequality in the durations of t_1 and t_2. For equal t_1 and t_2 an increase in either t_1 or t_2 either improved performance or had little or no effect on it. This result is to be contrasted with that obtained by Eriksen and Collins (1967): they found that performance of an integration task decreased as a function of increases in the duration of either t_1 or t_2. The present results indicate that, in comparison to performance with equal t_1 and t_2, decreasing either t_1 or t_2 produces either a decrease in performance or little or no effect on performance. A decrement in performance with decreasing t_1 and t_2 is consistent with an effect of inequality. However, since Eriksen and Collins (1967) didnot employ this manipulation no direct comparison with their results can be made. Furthermore the overall pattern of results in the present experiment suggests that this effect is part of an overall tendency for performance to decrease with decreasing exposure duration and not an effect of inequality as such. It should be noted that if this interpretation of the present results is accepted it would also rule out the possibility that unequal exposure durations had a beneficial rather than a detrimental effect on performance of the task.

The results of the present study do not rule out the possibility that event perception based on integrative processes may be evident under conditions other than those of the present experiment. The hypothesis advanced for the present experiment was encouraged by a tachistoscopic pilot study. The stimuli used in the pilot study were similar to those used in the present experiment and were composed of black dots inked on white card. Informal observation of these stimuli under tachistoscopic exposure conditions indicated that at short, equal durations of t_1 and t_2 a three-dot target stimulus appeared faded in comparison to non-target dots and was thus perceptible. Under these conditions an effect of inequality was observed: in comparison to its perceptibility with equal t_1 and t_2, increasing or decreasing either t_1 or t_2 appeared to reduce the perceptibility of the target. After the results of the present experiment were known the tachistoscopic exposure conditions were examined in some detail. This examination suggested that at least three conditions were necessary before the phenomenon could be reliably observed. Firstly, target dots appeared faded only when equal t_1 and t_2 durations of less than 16 msec were employed. Secondly, it seemed to require that target dots were large (greater than 0.5°) and were embedded in relatively few non-target dots. Thirdly, perceptibility of the target was greatly enhanced if the entire stimulus sequence was repeated at approximately 1 sec intervals (cf Haber, 1969). The pilot observations suggest that the hypothesis advanced for the present experiment might merit further investigation. However, they also suggest that if event perception based on integration is possible it can only be observed under conditions very carefully designed to elicit it.

The results indicate that the effects of t_1 and t_2 on the perception of appearances and disappearances are symmetrical. A plausible explanation for this symmetry is that it corresponds to a symmetry in the conditions of stimulation. For appearances t_1 is the duration of the pattern without the target while t_2 is the duration of the pattern with the embedded target, on the other hand for disappearances t_2 is the duration of the pattern without the target while t_1 is the duration of the pattern with the target. It is perhaps not surprising that performance should improve with increases in the duration of the target (t_2 for appearances, t_1 for disappearances). However, in the present experiment the effect of the duration of the target on performance was less marked that the effect of the duration of the pattern without the target (t_1 for appearances, t_2 for disappearances).

Phillips and Singer (1974) report an improvement in the detection of events with increases in t_1 for appearances and t_2 for disappearances. As previously discussed, their explanation for this result is framed in terms of the effects of t_1 and t_2 on the neural coding of the gap between the first and second patterns. Phillips and Singer obtained this result with ISIs between patterns of 40 and 100 msec. They report that ISIs of 40 msec or more produced a clearly visible interruption. However, in the present experiment there was an ISI between patterns of only 5 msec and no interruption was visible. It thus seems unlikely that the present result can be explained in terms of the effects of t_1 and t_2 on the coding of the gap between patterns.

An alternative possible explanation for the effects of t_1 on appearances and t_2 on disappearances rests on the fact that they represent the intervals between the events and the corresponding appearance or disappearance of the entire pattern. For appearances t_1 + ISI is the interval between the onset of the random dot pattern and the onset of the target. For disappearances t_2 + ISI is the interval between the offset of the target and the offset of the random pattern. It seems reasonable to suppose that the perception of a target defined by appearances will be impaired in so far as the appearance of the target is perceived as simultaneous with the appearance of the pattern and that the likelihood of this happening will increase as the interval between pattern onset and target onset is decreased. Thus the improvement in performance with increases in t_1 for appearances may be due to an increase in the temporal separation between the appearance of the pattern and the appearance of the target. Similarly, the improvement in performance with increases in t_2 for disappearances may be due to an increase in the temporal separation between the disappearance of the target and the disappearance of the pattern.

The explanation proposed above for the effects of t_1 on appearances and t_2 on disappearances does not suggest an obvious explanation for the complex interactions between exposure durations indicated by the results. However, this explanation does suggest a possible parallel between the present paradigm and the Eriksen and Collins paradigm. The essence of the above explanation is that performance of an event perception task is impaired in so far as target events are integrated with the corresponding onset or offset of the pattern. It is possible that this form of integration is also evident in the Eriksen and Collins paradigm. The task employed by Eriksen and Collins requires integration of stimuli rather than simply integration of onsets and offsets. Nonetheless it is a plausible hypothesis that integration of stimuli will be affected by the extent of integration of onsets and offsets. As was noted in the Introduction the integration evident in the Eriksen and Collins paradigm may include a number of different kinds of integrative process.

3.4 Experiment VII: The perception of patterns of events involving both appearances and disappearances

The results of Experiments IV and V are regarded as indicating that onset and offset of a pattern convey information concerning pattern form and the relative positions of the elements of the pattern. It was argued above that the ability to perform recognition and localization tasks with appearances and disappearances indicates that information concerning the target is stored. Of particular interest here is the claim that information is stored after pattern offset. The evidence for this storage was obtained at t_1 durations of 480 and 495 msec in Experiments IV and V respectively. Thus this storage is evident at relatively long stimulus durations. The present claim thus conflicts with the results of studies suggesting that storage is evident only at short stimulus durations. The question arises of whether these conflicting results can be reconciled.

Evidence that there is little, if any storage at long (circa 500 msec) stimulus durations comes from studies employing probe matching (Haber and Standing, 1970; Efron, 1970 c) and subtractive reaction time (Briggs and Kinsbourne, 1972) techniques. These studies were discussed in the Introduction. Probe marching and subtractive reaction time paradigms require subjects to make a judgement concerning the occurrence of the offset of the stimulus. It may be that the storage evident in these paradigms represents a delay in the apparent offset of the stimulus. There is physiological evidence (e. g. Schiller, 1969) that there is a delay in the off - response at short stimulus durations which decreases as stimulus duration increases and is negligible at long stimulus durations. The event perception paradigm, on the other hand, requires a judgement to be made concerning the form of the target stimulus. This judgement must be made after the apparent offset of the target since it is by its apparent offset that the target is detected. It was argued that the results of Experiments IV and V are evidence that the event signal conveys information concerning the location of the event and is sufficiently extended in time to be utilized by perceptual processes. Thus there may be a very simple explanation for the discrepancy between the results from, on the one hand, probe matching and subtractive reaction time studies and, on the other, the event perception paradigm: storage in the former case may reflect a delay in the visual response to stimulus offset while storage in the latter paradigm may reflect an extended response to stimulus offset.

The above considerations suggest that the results from probe matching and subtractive reaction time studies may not be in direct conflict with the present argument for storage in the event perception paradigm. There is also, however, a conflict between the results of the present experiments and studies of visual integration which is less easily reconciled. Unlike probe matching and subtractive reaction time techniques the Eriksen and Collins paradigm requires information concerning the form of a pattern to be used. As mentioned in the introduction to Experiment VI, sensory storage is not observed in the Eriksen and Collins paradigm at long stimulus durations. This result appears inconsistent with the arguments presented here concerning storage in the event perception paradigm. The present claim is that information concerning the form of a pattern is stored after its apparent offset. The question arises of why, in the Eriksen and Collins paradigm this information cannot be combined with an aftercoming pattern to allow perception of a composite.

If the present arguments are correct, performance of the Eriksen and Collins task at long t_1 durations would involve combining information concerning the disappearance of the first pattern with an appearing second pattern. A similar, though not identical task can be arranged in the present paradigm by requiring subjects to combine information from both disappearances and appearances. The hypothesis for the present experiment was that mixing appearances and disappearances would impair the organization of a composite. The subjects' task in the present experiment was similar to that in Experiments V and VI: judging whether three events were aligned or not. The three events could be appearances, disappearances or a mixture of both appearances and disappearances. If the organization of a composite is unaffected by mixing appearances and disappearances performance for mixtures of events should be intermediate between performance for appearances and disappearances alone. On the other hand if the organization of a composite is impaired by mixing appearances and disappearances performance for mixtures of events should be poorer than for either appearances or disappearances alone.

Method

Subjects: Subjects were 20 Stirling University undergraduates with normal or corrected to normal vision. Participation fulfilled a course requirement.

Stimuli: The stimuli employed in the present experiment were similar to those used in Experiments V and VI. Target stimuli were three dots which could be either in alignment or not in alignment. When the dots were not in alignment the lateral displacement of the central dot was 23.2'. The outer, reference dots subtended $3^{\circ}37'$.

The position and orientation of the target on the display surface were varied in the manner described for Experiment V: the midpoint of the target was located at random between + 43.5' and - 43.5' from the screen centre; the three dots were then rotated about the screen centre to a randomly determined orientation of between 0^{o} and 359^{0}. The target stimulus configuration was thus plotted within a circle of diameter $3^{o}55'$ on screen centre.

As in previous experiments the target dots could be embedded within or subtracted from random dot patterns. The stimulus patterns were generated by replacing and/or deleting dots in the random patterns. The type of pattern used in this experiment was identical to that used in the two preceeding experiments; a random dot pattern plus target stimulus comprised 100 dots plotted within a $7^{o}13' \times 7^{o}13'$ square.

The variable in this experiment was the types of event which defined the target stimulus. There were six exposure conditions. The first two presentation conditions were identical to the first two presentation conditions described for Experiments V and VI. Under these two conditions the target was defined by three events of the same kind: either appearances or disappearances. Targets were also defined by mixtures of appearances and disappearances. All possible combinations of appearances and disappearances yielded four conditions in which the target was defined by a mixture of events. The six exposure conditions were as follows (the types of event defining the target are indicated schematically thus: 0 - appearance; X - disappearance):

(1) Target defined by appearances: all target dots appear (000).

(2) Target defined by disappearances: all target dots disappear (XXX).

Target defined by mixtures of events:

(3) Outer dots appear, inner dot disappears (0 X 0).

(4) Outer dots disappear, inner dot appears (X 0 X).

(5) One outer dot and the inner dot appear, other outer dot disappears (00X).

(6) One outer dot and the inner dot disappear, other outer dot appears (XX0).

Under all exposure conditions $t_1 = t_2 = 495$ msec, achieved by giving each pattern 100 successive refreshes at 5 msec intervals. There was an ISI between patterns of 5 msec.

Procedure: Subjects were instructed that reaction times were being recorded but that accuracy was most important. The sequence on each trial was identical to that described for Experiment IV. The subjects' task was again to indicate whether the target dots were in alignment or not. On half the trials the target dots were in alignment and on half the trials they were not.

Subjects performed 32 trials under each of the six exposure conditions: on 16 trials the dots were in alignment and on 16 trials they were not. The 20 subjects thus contributed a total of 640 observations per condition. Order of trials was determined by random selection without replacement from the total set trials for that subject. There was a practice at the beginning of each session consisting of 16 trials under each condition. During the practice the machine indicated correct and incorrect responses.

Results

Percentages of correct response are shown in Figure 3.10 as a function of the types of event which defined the target. Chance performance in this figure is 50% correct. An analysis of variance was performed on the number of correct responses in accordance with a one - way repeated measures design. There was a highly significant effect of exposure condition, $F(5,95) = 23.30$, $p < 0.001$. Two planned comparisons (Hays, 1969) of performance under the six exposure conditions were carried out. The mean number of correct responses for targets defined by appearances alone was significantly greater than the average of the means for targets defined by mixtures of events, $t = 10.56$, $df = 95$, $p < 0.01$ (one - tailed). Furthermore, the mean number of correct responses for targets defined by disappearances was also significantly greater than the average of the means for targets defined by mixtures of events, $t = 2.461$, $df = 95$, $p < 0.01$ (one - tailed). As can be seen from Figure 3.10 performance for targets defined by mixtures

FIGURE 3.10

Experiment VII. Percentages of correct responses under each exposure condition. The types of event which defined the target stimulus under each condition are indicated schematically. Chance performance is 50% correct.

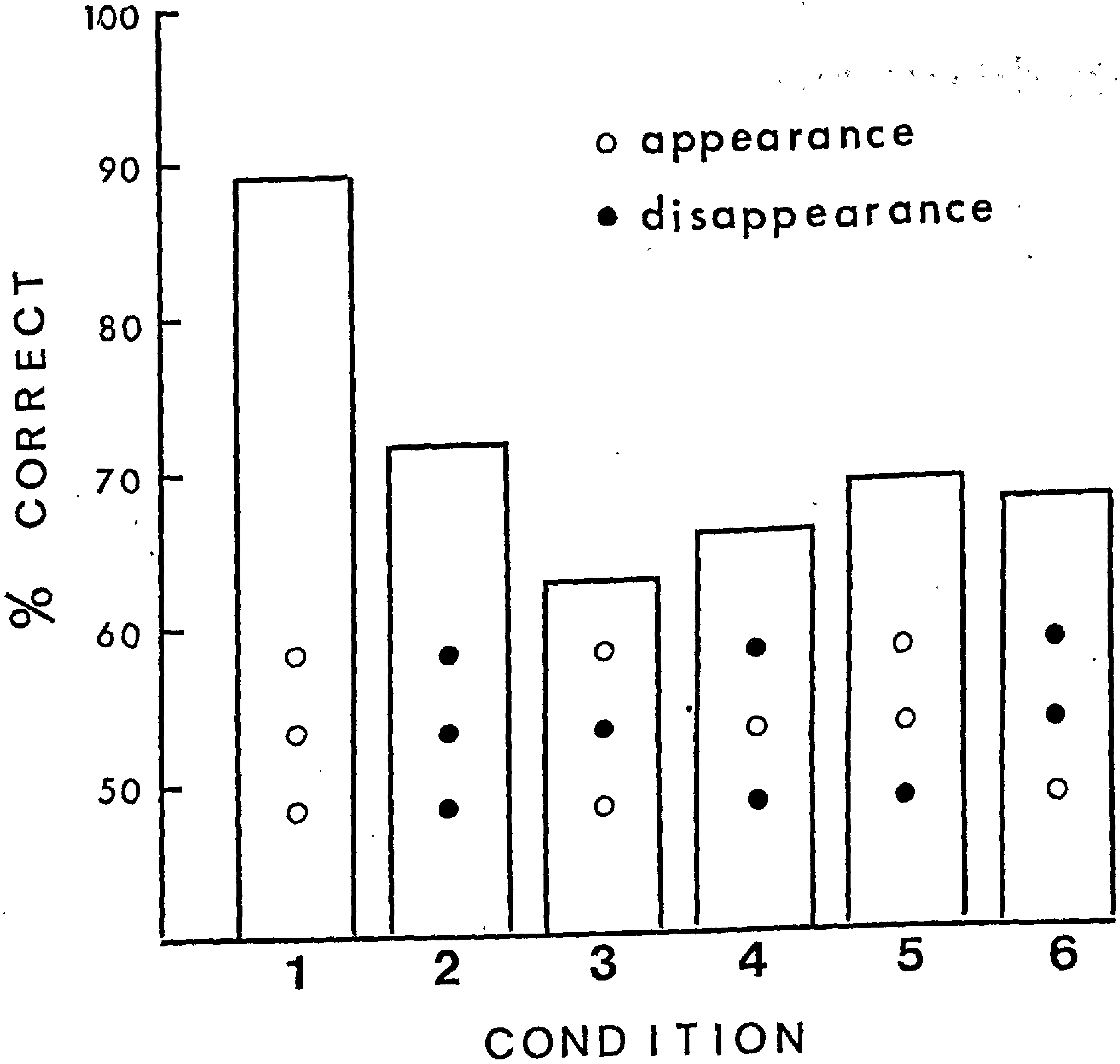

100
90
80
70
60
50
% CORRECT
○ appearance
● disappearance
1
2
3
4
5
6
CONDITION

Fig 3.10 [illegible]

of events is poorer than for either appearances or disappearances alone. A follow up analysis indicated that the means for targets defined by mixtures of events were not reliably different from each other (Scheffe test, $\alpha = 0.05$). However, all means were reliably above chance (Z test, $\alpha = 0.05$).

Mean reaction times and 0.05 confidence limits of correct responses under each of the exposure conditions are shown in Figure 3.11. As can be seen there is a trend towards longer reaction times for targets defined by mixtures of events.

Discussion

The results show that performance in a localization task is poorer for targets defined by mixtures of appearances and disappearances than for target defined by either type of event alone. The results thus confirm the hypothesis that mixing appearances and disappearances impairs the organization of a composite. The results also indicate that it is possible to perform the present task with targets defined by mixtures of appearances and disappearances. Thus as they stand the present results can only partially account for the failure to observe storage in the Eriksen and Collins paradigm at long stimulus durations. However, an argument can be advanced that the discrepancy between the paradigms is due to differences in the natures of the tasks.

FIGURE 3.11

Experiment VII. Mean reaction times and 0.05 confidence limits of correct responses under each exposure condition. The types of event which defined the target under each condition are indicated schematically.

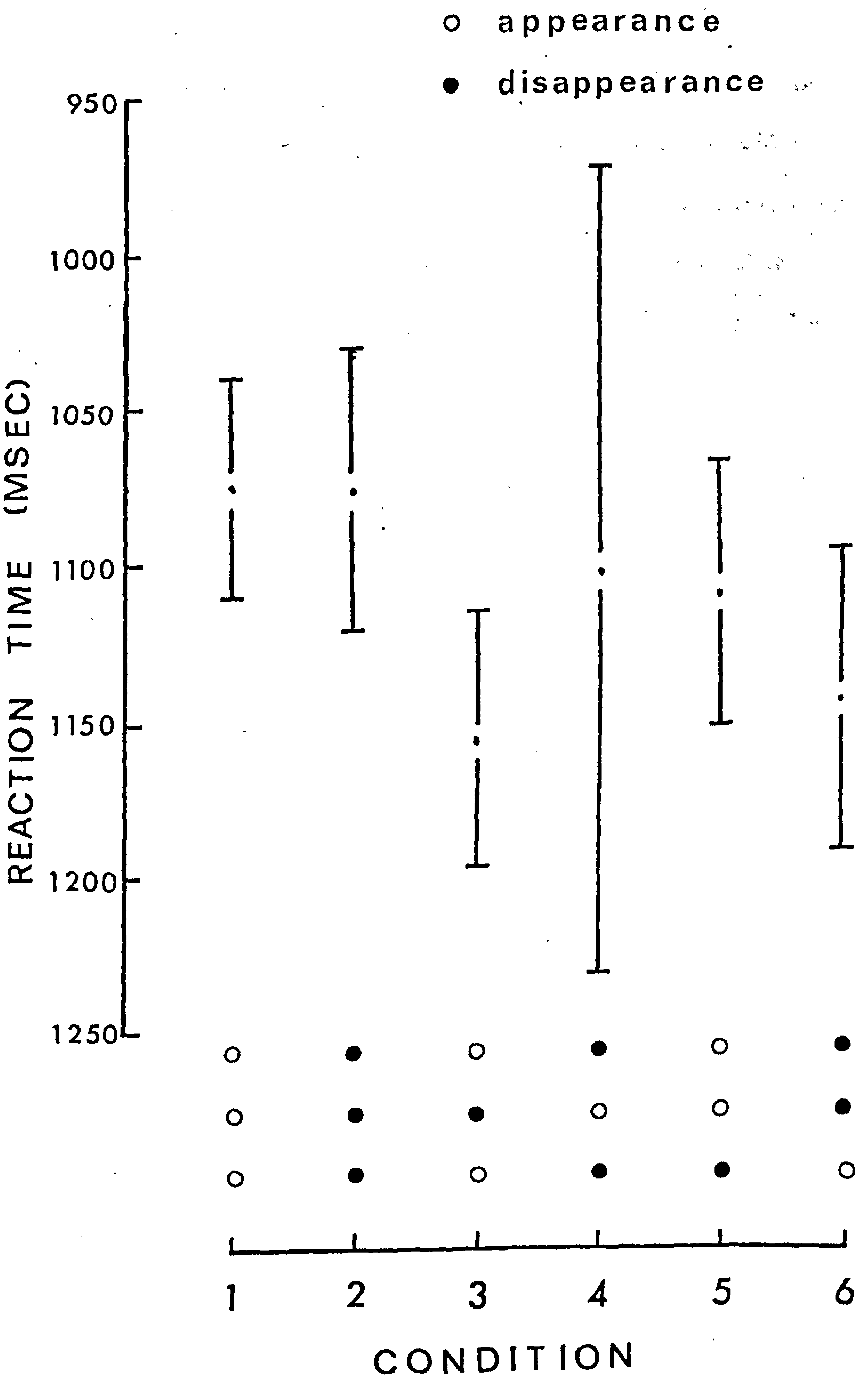


Fig 3.11 composite legend on p 166

Mixtures of appearances and disappearances produced a strong phenomenal impression of apparent movement; such an effect was not observed with targets defined by events of the same kind. The precise pattern of movement depended on the particular combination of appearances and disappearances; however, the general direction of movement was from disappearance to appearance. As mentioned earlier, Pollack (1972 a, b) has used very similar stimulation to study apparent movement. Pollack (1972 a) reports that the direction of apparent movement from a disappearance to an appearance can be reliably discriminated. Performance of the present task may have been aided by the ability to discriminate the direction of apparent movement; the task could be performed by judging whether the pattern of movement was produced by events which were aligned or misaligned. Thus performance for targets involving both appearances and disappearances may reflect the ability to discriminate the direction of apparent motion.

Whether, and to what extent, mixing appearances and disappearances impairs performance of a task requiring perception of form may well depend on the extent to which apparent motion interferes with performance of the task. In the present experiment apparent movement appeared to impair organization of a composite; however, the task was still possible. On the other hand the stimuli employed by Eriksen and Collins might be expected to produce a much more complex pattern of movement and thus a greater impairment of performance at long stimulus durations. Again, the stimuli used by Julesz (1971) and Lappin and Bell probably created apparent motion. However, the subjects' task in these studies did not require the location of individual changes, only the identification of an area of change within a static background. Here apparent movement would serve to distinguish the area of change from the unchanged background.

The relation between the perception of simple events and the perception of movement clearly merits further study. An initial investigation might be made into the spatial and temporal relationships between events of the same or different kinds which are sufficient and/or necessary to produce apparent movement. The notion of a link between the perception of simple events and apparent motion suggests a further possible function of an event perception system. The ability to locate events demonstrated in Experiment V may serve in the computation of the position and direction of movement.

3.5 General discussion of the experiments on event perception

3.5.1 Limits of event perception

Experiment IV investigated whether letters defined by patterns of events could be recognized. The results showed that letters defined by either appearances or disappearances could be accurately identified. The finding that letters defined by disappearances could be recognized is particularly surprising: it implies that a pattern which is not visible is made visible by its disappearance. The experiment demonstrates a capacity rather than a limit of the ability to perceive events and can thus be regarded as providing further evidence that this ability is highly developed. The capacity demonstrated by Experiment IV suggests that one function of an event perception system may lie in the recognition of patterns of events. It was noted that it would clearly be advantageous for an organism to know not only that a change had taken place but also the form of the change.

Experiment IV did not indicate how fine a discrimination of form could be made on the basis of appearances and disappearances. However, the results showed that performance for letters defined by disappearances was poorer than for letters displayed alone, the results also suggested that the same might be true for letters defined by appearances. Experiment V investigated the accuracy with which the relative position of detected events is specified. The results showed that performance for targets defined by disappearances was poorer than for targets defined by appearances, which in turn was poorer than for targets presented alone. Thus the relative position of an event is not as accurately specified as the relative position of a sustained stimulus. The experiment did not allow the absolute acuity of the event perception system to be estimated. However the results suggested that even if the event perception system cannot accomplish a fine discrimination of form it could still function to direct selective processes to areas of change.

Experiments IV and V represent only an initial investigation of the limits and capacities of the event perception system. It is worth briefly considering ways in which such an investigation might be extended. The task employed in Experiment V was only one of a number of tasks which could be used to investigate the acuity of the system. Thus, for example, the discrimination acuity of the system could be studied using a task requiring subjects to indicate whether two events were contiguous or not. Again, recognition acuity could be studied with a task similar to that employed in Experiment IV: performance of a letter recognition task could be investigated as a function of letter size. In addition to there being a number of possible tasks it would also be of value to investigate the conditions affecting performance of these tasks. It was argued that the results for targets exposed alone in Experiment V indicated that conditions of stimulation in this experiment were sub - optimal. The relatively poor performance for targets exposed alone was probably partly due to the inaccuracy of the display system; doubtless the accuracy of conditions of presentation could be improved. However, it would also be of interest to study whether performance of this task was improved by, for example, decreasing the separation between the outer dots. Similarly, thought might be given to the optimization of the conditions of stimulation in other tasks designed to investigate the acuity of the event perception system. Finally, such an investigation would benefit from an experimental design in which a larger number of observations were made by individual subjects, thus allowing the precise extent of individual differences to be estimated.

The aim of Experiment VI was to investigate whether integrative processes similar to those delineated by Eriksen and Collins were evident in the event perception paradigm. The experiment did not attempt to have any ecological validity thus discussion of this experiment will be confined to the succeeding section. Similarly the primary aim of Experiment VII was clarification of the relationship between event perception and sensory storage, however, the results of this experiment are of some interest here. Experiment VII compared performance of a localization task with targets defined by appearances, disappearances and mixtures of appearances and disappearances. The results showed that performance of this task was poorer with targets defined by mixtures of events than with targets defined by either type of event alone. It was observed that targets defined by mixtures of events produced a strong impression of apparent movement. It was argued that apparent movement was responsible for the poorer performance of the localization task with targets defined by mixtures of events. The observation that mixtures of appearances and disappearances produce apparent motion suggests another possible function of the ability to localize simple events: this ability may serve in the computation of the position and direction of movement.

The question of the relation between the perception of simple events and the perception of real and apparent motion clearly merits further study. It is perhaps not surprising that apparent motion was observed between events of different kinds in Experiment VII since a number of studies of apparent movement have used similar stimulation (Anstis, 1970; Braddick, 1973; 1974; Julesz, 1971; Pollack, 1972 a, b). However, it appears that little thought has been given to the question of whether motion perception depends on the perception of simple events. It was suggested that an initial investigation might be made into the spatial and temporal relationships between events of the same or different kinds which are sufficient and/or necessary to produce apparent movement. It would be of some interest to know, for example, whether movement perception under present conditions of stimulation obeyed Korte's Laws (cf Kolers, 1972).

3.5.2 Event perception and sensory storage

Experiment IV demonstrated that letters defined by either appearances or disappearances could be recognized. It was noted that the finding that letters defined by disappearances can be identified is evidence against the hypothesis that detection of disappearance serves to terminate storage of information concerning form. Experiment V showed that a task requiring localization of the relative positions of detected events can be performed. The finding that recognition and localization tasks can be performed with events is regarded as evidence that information concerning events is stored. The argument for this conclusion is similar in form to one of the arguments considered in the Introduction for the orthodox view of the function of sensory storage. As noted in the Introduction, it is often argued that a sensory buffer is required because there is a change in rate/capacity of processing in the visual system. It was objected in the Introduction that a buffer is only required if stimuli are not otherwise maintained. However, although storage need not be necessary for the processing of sustained, normally fixated stimuli, it is required for the utilization of information concerning brief stimuli. The present argument is essentially that since simple events are very brief stimuli utilization of information concerning them will involve storage. The present evidence for sensory storage in the event perception paradigm is thus indirect in that it depends on certain assumptions concerning the differences between sensory and perceptual processes. In particular it is assumed that only sensory processes have a sufficient rate and capacity of operation to store information concerning events and furthermore, as a corollary, that any perceptual process will take an appreciable length of time.

The properties of the storage evident in the event perception paradigm clearly merit further study. It is worth briefly considering the form that such an investigation might take. The decay characteristics of the storage evident in the event perception paradigm could be studied by introducing a delay or delays into the sequence of events defining the target. Target stimuli, for example, could be similar to those employed in Experiment V or perhaps preferably composed of three letters rather than one (c f Eriksen and Collins, 1967; 1968). These target configurations could be divided into two complementary halves in a manner similar to that described by Eriksen and Collins and embedded in random dot patterns. Performance of a recognition task could then be investigated as a function of delays between the appearance (disappearance) of the first half target and the appearance (disappearance) of the second half target. A pilot study was conducted into the feasibility of such an experiment. Target stimuli were the three - dot stimuli employed in the present experiments. It was discovered that such stimuli were too simple for general use in such a study. However, with a careful choice of target parameters it was possible to obtain a decay curve for disappearances. The results suggested that performance of a localization task decreased as a function of the delay between the disappearance of the central dot and the disappearance of the outer dots, apparently asymptoting at chance at between 200 and 300 msec.

The paradigm suggested above might also be used to investigate some of the issues raised but only partially resolved in Experiment VII. In the introduction to Experiment VII it was suggested that there was a conflict between the results of probe matching and subtractive reaction time studies and the present claim that information concerning a long duration pattern is stored after pattern offset. It would be of interest to apply probe matching and subtractive reaction time techniques in the above paradigm and thus verify whether there is in fact a discrepancy between the estimates of storage obtained by these methods and by introducing delays into the sequence of disappearances defining a target. It would also be of interest to discover whether the estimates of storage obtained by the different methods were differently affected by varying stimulus duration. Furthermore, the primary aim of Experiment VII was to investigate an apparent conflict between present results and studies of visual integration. It was noted that storage was not observed in the Eriksen and Collins paradigm at long stimulus durations. The hypothesis advanced for Experiment VII was that mixing appearances and disappearances impairs the organization of a composite. The results confirmed that performance of a localization task with targets defined by mixtures of events was poorer than with targets defined by either type of event alone. However, performance was still above chance for targets defined by mixtures of events. It was argued that the creation of apparent motion was responsible for the impairment of performance with these targets. It was suggested that mixing appearances and disappearances and the consequent production of apparent motion may result in a greater impairment of performance with stimuli such as those used by Eriksen and Collins. The paradigm suggested above would allow this hypothesis to be tested: performance of a recognition task could be investigated with three letters defined partly by appearances and partly by disappearances.

Consideration has been given to apparent conflicts between the present claim that the disappearance of a pattern conveys information concerning the form of the pattern and the results of other studies of storage. It should also be noted that the present claim may have implications for studies of storage with which it is not in conflict. In particular, the storage evident in the event perception paradigm may be involved in other paradigms requiring utilization of information concerning the form of a stimulus. Thus, for example, the present storage may be involved in the partial report paradigm. The present paradigm could in fact be regarded as a post - stimulus sampling paradigm in which the target is cued by its disappearance rather than by a tone (Sperling, 1960) or by a bar marker Averbach and Coriell (1961) . The stimuli used in the present study are, of course, rather different from those normally employed in partial report studies. It would thus be of some interest to investigate whether a single, conventional letter which disappeared from an array of similar letters could be identified.

Experiment VI attempted to obtain evidence for an integration model of event perception. The specific hypothesis tested by this experiment was that the integrative processes delineated by Eriksen and Collins (1967; 1968) would be evident at short durations of t_1 and t_2 in the event perception paradigm and would allow performance of an event perception task. Eriksen and Collins (1967) present evidence that integration is adversely affected by inequality in the duration of the two stimulus halves. There was little or no evidence for an effect of inequality in Experiment VI; rather the results suggested that there was an overall tendency for performance to decrease with decreasing exposure durations. Thus the results of Experiment VI did not support the hypothesis that the integrative processes proposed by Eriksen and Collins allow performance of an event perception task at short presentation durations. The results of a pilot study suggested, however, that this hypothesis might merit further investigation.

The relationship between the present paradigm and the Eriksen and Collins paradigm remains unclear. For the purposes of Experiment VI it was assumed that Eriksen and Collins' interpretation of their results was essentially correct. In particular it was assumed that Eriksen and Collins were correct in arguing that integration is associated with an effect of inequality between the energy of the stimulus halves. However, it was noted in the Introduction that the concept of integration as employed by Eriksen and Collins appears to subsume at least two rather different kinds of integrative process: energy summation and a process of global perceptual integration. Furthermore Eriksen and Collins (1967) note that the effects of varying presentation duration and order of long and short halves on performance in their paradigm are not entirely consonant with their notions of integration and persistence. Thus clarification of the relationships between the present paradigm and the Eriksen and Collins paradigm may await clarification of the apparently rather complex processes involved in the latter paradigm.

CHAPTER 4: GENERAL CONCLUSIONS

Two main aims for the present study were outlined in the Introduction. The first was to investigate some of the limits of the ability to detect appearances and disappearances and perceive patterns of such events. It was hoped that this investigation might contribute to an understanding of the function of an event perception system. The second was to investigate the relationship between sensory storage and the detection and perception of simple events.

4.1 Limits of event detection and perception

Experiment I showed that small changes in complex stimuli were highly detectable despite manipulation of number of elements, size of pattern and separation between elements. Under only one condition was a limit to performance approached: that in which 1024 dots were displayed within $4^{o}38' \times 4^{o}38'$. It was hypothesized that an event detection system might allow the detection of significant change in the natural environment. It was argued that the finding that a limit to performance was approached when a large number of dots were plotted in a small area is not inconsistent with this hypothesis: it is not necessarily advantageous to be sensitive to relatively small changes in the visual environment. Experiment II showed that events were highly detectable in stimuli which were not of uniform luminance. The results of the first two experiments are regarded as evidence that the event detection system is highly developed and largely unaffected by sources of variation in the stimulus array such as are liable to be encountered in the natural environment.

Experiment III examined the hypothesis that the event detection system is particularly designed to detect changes occurring during interruptions. The results appeared to disconfirm this hypothesis. The short duration of storage found in this study would suggest that it is possible to detect changes occurring during only the briefest of interruptions.

The second series of experiments examined the ability to recognize patterns of events and discriminate the relative visual direction of events. Experiment IV investigated whether it was possible to recognize letters defined by events. The results showed that letters defined by either appearances or disappearances were accurately identified. The experiment is regarded as providing further evidence that the ability to process events is highly developed. The findings of this experiment suggest that one function of an event perception system may lie in the recognition of patterns of events. Experiment V investigated the ability to localize the relative positions of events. It was found that the position of events was less accurately specified that the position of sustained stimuli. The results suggested, however, that the acuity of the event perception system is high enough to direct selective processes to areas of change. Experiment VII investigated performance of a localization task with targets defined by mixtures of appearances and disappearances. The results showed that mixing appearances and disappearances impaired the ability to organize events into a composite. It was argued that apparent movement was responsible for poorer performance with such targets. The observation that mixtures of events produce apparent motion suggests another possible function of the ability to localize simple events: this ability may serve in the computation of the position and direction of movement. Three possible functions of an event perception system are therefore suggested:

(1) Recognition of patterns defined by events.
(2) Directing selective processes.
(3) Movement computation.

4.2 Event detection, perception and sensory storage

The first series of experiments concerned the ability to detect simple events. It was noted in the Introduction that event detection involves sensory storage. It is generally assumed that sensory storage is associated with integrative processes in the visual system. A possible explanation of event detection in terms of such processes was outlined. The basis of this explanation was that a change in stimulus conditions is marked by an attenuated visual signal. It was also argued, however, that sensory storage need not be associated solely with integrative processes. An alternative explanation of the ability to perform an event detection task was framed in terms of processes of differentiation, that is, processes which enhance successive contrast. Such an explanation implies that a change is marked by a distinct, active visual signal. The results of Experiments I and II are regarded as supporting a differentiation model of event detection. Differentiation theory predicts that a high level of performance will be achievable in an event detection task and that this performance will be largely unaffected by manipulation of the steady state properties of the stimulus array. Experiments I and II confirmed that highly accurate performance could be obtained in the event detection paradigm and that performance was largely unaffected by varying number of dots, size of array, separation between dots and by whether the luminance of the dots in the pattern was homogeneous or not. Under only one condition was a sizeable decrement in performance observed: that in which a large number of dots (1024) were displayed within a small area ($4^{o}38' \times 4^{o}38'$). Furthermore the results of Experiment II are regarded as militating against an integration hypothesis. In so far as an integration theory implies that areas of change are identifiable by having an intermediate brightness it predicts that performance will be adversely affected by inhomogeneity in the luminance of surrounding areas. No evidence for such an effect was found in Experiment II. Thus the results of Experiments I and II are regarded as favouring an explanation of event detection in terms of differentiation rather than integration.

It was noted that the high level of performance which could be achieved with patterns containing 1024 dots in Experiment I is evidence that the storage involved in event detection is very high capacity. Experiment III investigated the effect of ISI and pattern complexity on performance of an event detection task. The results confirmed that high capacity, short duration storage was involved in event detection. The curves obtained for simple and complex patterns were different. However, it was argued that these differences could be attributed to factors other than an effect of complexity on sensory storage.

The second series of experiments concerned the ability to recognize patterns of events and to localize the relative positions of events. Experiment IV demonstrated that letters defined by either appearances or disappearances could be recognized. The finding that letters defined by disappearances can be identified is regarded as evidence against the hypothesis that detection of disappearance serves to terminate storage of information concerning form. Experiment V showed that a task requiring localization of the relative positions of detected events could be performed. The results of these experiments are regarded as evidence that information concerning events is stored. The argument for this conclusion is, briefly, as follows: in these experiments target stimulus configurations were defined by the difference between two successive random dot patterns. Either pattern alone gave little or no information concerning the target and the appearance or disappearance of the target took place practically instantaneously. However, the perceptual processes which accomplish recognition or localization processes are assumed to require time. Thus the finding that it is possible to perform recognition or localization tasks is regarded as evidence that the event signal conveys information concerning the relative position of the event and furthermore that this signal is sufficiently extended in time to be utilized by perceptual processes.

Experiment VI attempted to obtain evidence for an integration model of event perception. It was noted that there is a marked similarity between the event perception paradigm and the Eriksen and Collins paradigm. Eriksen and Collins (1967; 1968) propose that performance in their paradigm can be understood in terms of processes of persistence and integration. Thus, if performance of an event perception task were affected in a similar manner by the same variables as performance of Eriksen and Collins' task an integration model of event perception would be favoured. However, it was pointed out that storage is not observed in the Eriksen and

Collins paradigm at long stimulus duration while at similar stimulus durations performance of event detection and perception tasks could, under appropriate conditions, be maximal. Thus it seems unlikely that the integrative processes delineated by Eriksen and Collins could be responsible for performance of event detection and perception tasks at long stimulus durations. It was suggested that a more plausible hypothesis is that such integrative processes are evident at short stimulus durations in the present paradigm. Central to Eriksen and Collins' concept of integration is the notion that inequality in energy between stimulus halves impairs integration. Experiment VI thus investigated whether such an inequality effect was observed in the event perception paradigm at short stimulus durations. Performance of a localization task was studied as a function of varying the durations of t_1 and t_2 in a factorial design. There was little or no evidence for an effect of inequality in the durations of t_1 or t_2 on performance; rather the results indicated that there was an overall tendency for performance to decrease with decreasing exposure duration. The results thus did not support the hypothesis that event perception based on the integrative processes delineated by Eriksen and Collins is evident at short durations of t_1 and t_2 in the present paradigm.

Consideration was given in Experiment VII to an apparent conflict between the present arguments for storage in the event perception paradigm and the results of studies of visual integration. It was noted in the context of Experiment VI that storage is not observed in the Eriksen and Collins paradigm at long stimulus durations. However, one of the present claims is that the disappearance of a long duration pattern conveys information concerning the form of the pattern. The question arises of why, in the Eriksen and Collins paradigm, this information cannot be combined with an aftercoming pattern to allow perception of a composite. The hypothesis for Experiment VII was that mixing appearances and disappearances impairs the organization of a composite. Performance of a localization task was compared for targets defined by appearances, disappearances and mixtures of appearances and disappearances. The results showed that performance for targets defined by mixtures of appearances and disappearances was poorer than performance for either type of event alone. Although the results confirmed the hypothesis, performance for targets defined by mixtures of events was still above chance. It was argued that the source of the impairment of performance lay in the production of apparent motion. It was suggested that the pattern of apparent motion produced by Eriksen and Collins stimuli would be more complex and produce a greater impairment of performance that that observed with the present stimuli.

The most general conclusion from the investigation of the limits of event perception is that event perception is a highly developed visual function. Similarly, from the study of the relationship between event perception and sensory storage it is concluded that sensory storage is involved in both the detection and perception of events. It was noted in the Introduction that increasing scepticism is being voiced concerning whether sensory storage is of value in visual processing. In contrast to this scepticism it is concluded here that event perception is an important visual function in which sensory storage is clearly implicated.

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APPENDIX 1: SUMMARY TABLES

The tables summarise the data obtained in Experiments I-VII. For all Experiments except IV the tables have the same format.

Categories of response. The entries for each experimental condition are divided into five categories: misses, hits, correct rejections, false alarms and correct responses. These categories refer to the following types of response: Experiments I-III. Miss: response of 'no event' when there was an event. Hit: response of 'event' when there was an event. Correct rejection: response of 'no event' when there was no event. Correct response: a hit or a correct rejection. Experiments V-VII. Miss: response of 'straight' when the target was misaligned. Hit: response of 'bent' when the target was misaligned. Correct rejection: response of 'straight' when the target was aligned. False alarm: response of 'bent' when the target was aligned. Correct response: a hit or a correct rejection.

Entries in each cell. There are four entries per category per condition:

(1) Total number of responses in the category.

(2) Mean number of responses (total/subjects).

(3) Mean reaction time of responses in msec (sum RT/total).

(4) The standard error of the mean reaction time multiplied by 1.96. The 0.05 confidence limits of the mean RT are thus given by the mean RT plus or minus the stated value.

The maximum possible total and mean number of responses in each category are indicated at the head of each table.

EXPERIMENT I

Appearances No. of Dots	 Pattern Size	Misses	Hits	Correct Rejections	False Alarms	Correct Responses
		Max Total		130		260
		Max Mean		5		10
1024	Small	28 1.08 1646 325	102 3.92 648 44	126 4.85 1581 198	4 0.15 1629 1249	228 8.77 1164 126
	Medium	4 0.15 2466 2295	126 4.85 600 36	130 5 1625 179	0 0 - -	256 9.85 1121 112
	Large	5 0.19 1434 466	125 4.81 614 35	125 4.81 1853 220	5 0.19 2778 628	250 9.62 1233 135
256	Small	3 0.12 686 406	127 4.88 574 32	130 5 1484 165	0 0 - -	257 9.88 1034 101
	Medium	3 0.12 1126 598	127 4.88 596 55	130 5 1541 152	0 0 - -	257 9.88 1074 100

	Large	3 0.12 652 171	127 4.88 570 36	124 4.77 1732 191	6 0.23 1420 646	251 9.65 1144 120
64	Small	1 0.04 2215 -	129 4.96 538 25	130 5 1298 155	0 0 - -	259 9.96 919 91
	Medium	2 0.08 692 137	128 4.92 569 43	130 5 1363 132	0 0 - -	258 9.92 969 85
	Large	6 0.23 1414 399	124 4.77 561 27	129 4.96 1574 198	1 0.04 1119 -	253 9.73 1078 119
16	Small	2 0.08 550 71	128 4.92 531 23	130 5 1212 164	0 0 - -	258 9.92 874 93
	Medium	1 0.04 1644 -	129 4.96 536 27	130 5.00 1253 138	0 0 - -	259 9.96 896 83
	Large	3 0.12 1730 418	127 4.88 547 26	128 4.92 1341 141	2 0.08 680 62	225 9.81 945 87

Disappearances		Misses	Hits	Correct Rejections	False Alarms	Correct Responses
No. of Dots	Pattern Size					
		Max Total		130		260
		Max Mean		5		10
1024	Small	22 0.85 1221 297	108 4.15 629 43	128 4.92 1420 148	2 0.08 854 359	236 9.08 1058 96
	Medium	10 0.38 1530 506	120 4.62 640 46	129 4.96 1397 140	1 0.04 2152 -	249 9.58 1032 89
	Large	10 0.38 1541 414	120 4.62 622 31	130 5 1597 139	0 0 - -	250 9.62 1129 95
256	Small	8 0.31 1402 463	122 4.69 590 53	128 4.92 1351 127	2 0.08 1231 1177	250 9.62 980 84
	Medium	6 0.23 959 300	124 4.77 607 57	128 4.92 1397 122	2 0.08 2624 508	252 9.69 1008 84

	Large	9 0.35 1484 386	121 4.65 583 31	126 4.85 1629 172	4 0.15 1526 337	247 9.50 1117 111
64	Small	2 0.08 814 466	128 4.92 571 41	126 4.85 1215 101	4 0.15 1262 494	254 9.77 906 90
	Medium	3 0.12 1169 568	127 4.88 554 30	130 5 1315 108	0 0 - -	257 9.88 939 73
	Large	6 0.23 1829 486	124 4.77 585 33	130 5 1443 161	0 0 - -	254 9.77 1024 99
16	Small	3 0.12 1202 1191	127 4.88 559 32	129 4.96 1074 96	1 0.04 743 -	256 9.85 819 60
	Medium	4 0.15 915 567	126 4.85 572 29	129 4.96 1129 97	1 0.04 1037 -	255 9.81 854 61
	Large	4 0.15 1890 860	126 4.85 594 41	130 5 1195 110	0 0 - -	256 9.85 899 70

Additional patterns, separation = 8.4

Appearances No. of Dots	Misses	Hits	Correct Rejections	False Alarms	Correct Responses
	Max Total		60		120
	Max Mean		5		10
256	4 0.33 1930 903	56 4.67 584 47	59 4.92 1521 255	1 0.08 1480 0	115 9.58 1065 158
64	3 0.25 995 525	57 4.75 536 34	60 5 1580 283	0 0 - -	117 9.75 1071 174
16	2 0.17 1170 1462	58 4.83 525 36	58 4.83 1150 161	2 0.17 504 62	116 9.67 838 100

Disappearances	Misses	Hits	Correct Rejections	False Alarms	Correct Responses
No. of Dots	Max Total		60		120
	Max Mean		5		10
256	3	57	60	0	117
	0.25	4.75	5.00	0	9.75
	1248	625	1380	-	1013
	760	99	170	-	120
64	0	60	60	0	120
	0	5.00	5.00	0	10
	-	591	1103	-	847
	-	72	135	-	89
16	3	57	60	0	117
	0.25	4.75	5	0	9.75
	1315	552	1006	-	785
	926	39	124	-	78

EXPERIMENT II

	Appearances		Misses	Hits	Correct Rejections	False Alarms	Correct Responses
No. of Dots	Pattern Size	Pattern Luminance	Max Total		112		224
			Max Mean		8		16
64	Medium	Varied	2	110	111	1	221
			0.14	7.86	7.93	0.07	15.79
			664	464	830	455	648
			270	16	104	-	58
		Uniform	2	110	107	5	217
			0.14	7.86	7.64	0.36	15.50
			433	502	873	5245	685
			36	36	197	8980	102
	Large	Varied	1	111	112	0	223
			0.07	7.93	8	0	15.93
			1535	505	584	-	545
			-	30	503	-	253
		Uniform	2	110	109	3	219
			0.14	7.86	7.79	0.21	15.64
			1425	479	781	542	629
			441	20	43	131	31
256	Medium	Varied	3	109	110	2	219
			0.21	7.79	7.86	0.14	15.64
			797	485	783	769	635
			725	18	90	390	50

	Large	Uniform	3 0.21 771 332	109 7.79 509 25	112 8 803 80	0 0 - -	221 15.79 658 46
		Varied	3 0.21 770 252	109 7.79 523 49	111 7.93 853 66	1 0.07 189 -	220 15.71 689 47
		Uniform	3 0.21 758 224	109 7.79 499 19	112 8 815 73	0 0 - -	221 15.79 659 44

Disappearances			Misses	Hits	Correct Rejections	False Alarms	Correct Responses
No. of Dots	Pattern Size	Pattern Luminance	Max Total		112		224
			Max Mean		8		16
64	Medium	Varied	5 0.36 750 207	107 7.64 500 26	112 8 777 54	0 0 - -	219 15.64 642 36
		Uniform	3 0.21 803 416	109 7.79 513 52	112 8 785 56	0 0 - -	221 15.79 650 42

256	Large	Varied	7 0.50 743 138	105 7.50 511 29	112 8 809 55	0 0 - -	221 15.50 665 37
		Uniform	10 0.71 720 130	102 7.29 518 32	111 7.93 842 65	1 0.07 926 -	213 15.21 687 43
	Medium	Varied	3 0.21 904 49	109 7.79 504 33	110 7.86 669 276	2 0.14 1412 336	219 15.64 587 140
		Uniform	2 0.14 679 189	110 7.86 495 22	111 7.93 780 43	1 0.07 364 -	221 15.79 638 31
	Large	Varied	6 0.43 836 230	106 7.57 517 24	109 7.79 804 43	3 0.21 737 395	215 15.36 662 31
		Uniform	7 0.50 1008 255	105 7.50 534 30	109 7.79 864 61	3 0.21 677 220	214 15.29 702 41

EXPERIMENT III

Appearances		Misses	Hits	Correct Rejections	Flase Alarms	Correct Responses
Type of Pattern	ISI (msec)	Max Total		72		144
		Max Mean		4		8
Complex	22	19 1.06 1243 236	53 2.94 839 91	64 3.56 1483 158	8 0.44 1346 492	117 6.50 1175 114
	32	50 2.78 1216 163	22 1.22 1126 245	70 3.89 1357 156	2 0.11 1295 1219	92 5.11 1299 133
	52	65 3.61 1216 138	7 0.39 1076 206	63 3.50 1211 169	9 0.50 1172 440	70 3.89 1193 150
	72	66 3.67 1295 188	6 0.33 1080 214	66 3.67 1234 143	6 0.33 1009 122	72 4 1220 131
	112	67 3.72 1256 121	5 0.28 1383 517	67 3.72 1327 172	5 0.28 871 109	72 4 1332 162

	262	67 3.72 1324 166	5 0.28 1153 577	61 3.39 1291 169	11 0.61 1302 459	66 3.67 1278 161
Simple	22	3 0.17 770 451	69 3.83 722 81	71 3.94 1451 140	1 0.06 1648 -	140 7.78 1175 113
	32	1 0.06 2530 -	71 3.94 743 78	70 3.89 1305 137	2 0.11 1830 1260	141 7.83 1094 103
	52	17 0.94 1556 392	55 3.06 906 150	61 3.39 1224 116	11 0.61 1207 416	116 6.44 1117 96
	72	12 0.67 1278 347	60 3.33 1108 156	52 2.89 1248 147	20 1.11 1065 163	112 6.22 1189 108
	112	21 1.17 1175 187	51 2.83 887 100	48 2.67 1136 125	24 1.33 895 171	99 5.50 1038 89
	262	36 2 1008 223	36 2 1031 175	66 3.67 1092 131	6 0.33 1046 367	102 5.67 1076 106

Disappearances		Misses	Hits	Correct Rejections	False Alarms	Correct Responses
Type of Pattern	ISI (msec)	Max Total		72		144
		Max Mean		4		8
Complex	22	20 1.11 1102 305	52 2.89 881 104	70 3.89 1549 174	2 0.11 1333 653	122 6.78 1242 124
	32	59 3.28 1485 169	13 0.72 1035 288	68 3.78 1364 138	4 0.22 1100 195	81 4.50 1302 128
	52	68 3.78 1378 147	4 0.22 1025 270	66 3.67 1373 174	6 0.33 846 85	70 3.89 1354 166
	72	68 3.78 1498 158	4 0.22 1059 568	64 3.56 1388 164	8 0.44 931 253	68 3.78 1369 158
	112	64 3.56 1494 148	8 0.44 953 336	60 3.33 1378 169	12 0.67 1039 191	68 3.78 1314 156

	262	63 3.50 1357 144	9 0.50 755 299	61 3.39 1476 166	11 0.61 699 299	70 3.89 1393 163
Simple	22	8 0.44 1355 662	64 3.56 776 83	71 3.94 1513 155	1 0.06 1491 -	135 7.50 1251 124
	32	5 0.28 802 436	67 3.72 861 94	70 3.89 1343 131	2 0.11 1305 580	137 7.61 1165 100
	52	23 1.28 1126 318	49 2.72 932 141	58 3.22 1124 94	14 0.78 1277 359	107 5.94 1056 81
	72	29 1.61 1248 273	43 2.39 1068 180	56 3.11 1275 130	16 0.89 1090 220	99 5.50 1204 107
	112	23 1.28 1553 433	49 2.72 947 145	58 3.22 1219 124	14 0.78 879 169	107 5.94 1119 98
	262	37 2.06 1170 289	35 1.94 1085 157	68 3.78 1114 105	4 0.22 972 688	103 5.72 1107 88

EXPERIMENT IV

Exposure Condition	Total Number of Responses	Mean Number of Responses
Letter defined by appearances	182	15.17
Letter defined by disappearances	173	14.42
Letter alone	188	15.67
Embedded letter	23	1.92
Maximum	192	16

EXPERIMENT V

Exposure Condition	Displacement (minutes of arc)	Misses	Hits	Correct Rejections	False Alarms	Correct Responses
		Max Total		128		256
		Max Mean		8		16
Target defined by appearances	5.8	66 4.12 983	62 3.87 973	91 5.69 976	37 2.31 1139	153 9.56 975
	11.6	35 2.19 1011 146	93 5.81 843 51	100 6.25 922 58	28 1.75 1088 172	193 12.06 884 39
	23.2	7 0.44 860 236	121 7.56 822 54	112 7.0 895 48	16 1.0 1053 247	233 14.56 857 36
	34.8	3 0.19 722 208	125 7.81 739 33	121 7.56 841 52	7 0.44 1287 354	246 15.37 789 31
	46.4	1 0.06 686 -	127 7.94 696 31	122 7.62 759 40	6 0.37 975 346	249 15.56 727 25

Target defined by dis-appearances	5.8	71 4.44 944 100	57 3.56 994 90	73 4.56 1029 96	55 3.44 862 68	130 8.12 1014 67
	11.6	65 4.06 986 104	63 3.94 842 75	97 6.06 904 60	31 1.94 926 103	160 10 879 47
	23.2	46 2.87 921 101	82 5.12 806 56	106 6.62 893 64	22 1.37 843 115	188 11.75 855 44
	34.8	21 1.31 855 126	107 6.69 813 67	104 6.50 793 44	24 1.50 1032 198	211 13.19 803 40
	46.4	2 0.12 872 276	126 7.87 729 38	111 6.94 787 56	17 1.06 988 224	237 14.81 756 33
Target alone	5.8	55 3.44 939 69	73 4.56 1032 61	91 5.69 1016 63	37 2.31 1033 107	164 10.25 1023 44
	11.6	11 0.69 1070 219	117 7.31 920 55	104 6.50 997 61	24 1.50 1089 173	221 13.81 956 41

23.2	3	125	120	8	245
	0.19	7.81	7.50	0.50	15.31
	1169	857	945	1522	900
	777	52	53	402	37
34.8	1	127	125	3	252
	0.06	7.94	7.81	0.19	15.75
	879	774	852	609	813
	-	33	47	174	29
46.4	0	128	125	3	253
	0	8.0	7.81	0.19	15.81
	-	763	820	1238	791
	-	39	40	668	28

EXPERIMENT VI

Appearances t1	t2 (No. of refreshes at 5 msec intervals)	Misses	Hits	Correct Rejections	False Alarms	Correct Responses
		Max Total		72		144
		Max Mean		4		8
4	4	22 1.22 1244 234	50 2.78 1208 156	32 1.78 1401 410	40 2.22 1329 341	82 4.56 1283 186
	8	21 1.17 1403 232	51 2.83 1141 120	28 1.56 1257 265	44 2.44 1180 190	79 4.39 1182 122
	16	17 0.94 1132 230	55 3.06 1176 135	31 1.72 1222 219	41 2.28 1150 151	86 4.78 1193 116
	32	19 1.06 1282 220	53 2.94 1106 226	31 1.72 1442 293	41 2.28 1150 176	84 4.67 1230 181
8	4	18 1.0 1273 206	54 3.0 1141 258	32 1.78 1073 152	40 2.22 1208 183	86 4.78 1116 171

	8	8 0.44 1029 274	64 3.56 947 74	45 2.50 1016 122	27 1.50 1203 218	109 6.06 975 67
	16	14 0.78 1146 244	58 3.22 907 109	62 3.44 908 85	10 0.56 1088 257	120 6.67 908 68
	32	11 0.61 1487 901	61 3.39 891 83	61 3.39 787 73	11 0.61 1171 374	122 6.78 839 56
16	4	5 0.28 1045 508	67 3.72 1034 80	59 3.28 1057 127	13 0.72 984 152	126 7.0 1045 73
	8	4 0.22 869 210	68 3.78 932 70	71 3.94 929 68	1 0.06 1000 -	139 7.72 931 49
	16	4 0.22 1038 737	68 3.78 901 87	66 3.67 909 102	6 0.33 1830 1080	134 7.44 905 67
	32	5 0.28 1746 926	67 3.72 758 58	68 3.78 782 68	4 0.22 1017 367	135 7.50 770 44

32	4	9 0.5 1360 333	63 3.5 1024 69	67 3.72 1042 79	5 0.28 1108 451	130 7.22 1033 53
	8	3 0.17 1351 411	69 3.83 974 65	67 3.72 1098 204	5 0.28 1317 591	136 7.56 1035 106
	16	3 0.17 1031 169	69 3.83 979 81	70 3.89 910 51	2 0.11 1177 557	139 7.72 945 48
	32	3 0.17 1028 417	69 3.83 837 54	67 3.72 866 67	5 0.28 1220 840	136 7.56 851 43

Disappearances		Misses	Hits	Correct Rejections	False Alarms	Correct Responses
t1	t2					
(No. of refreshes at 5 msec intervals)		Max Total		72		144
		Max Mean		4		8
4	4	22 1.22 1325 232	50 2.78 1318 194	21 1.17 1367 251	51 2.83 1179 157	71 3.94 1333 155
	8	25 1.39 1315 189	47 2.61 1085 157	24 1.33 1455 390	48 2.67 1127 152	71 3.94 1210 171
	16	17 0.94 1027 177	55 3.06 1021 108	43 2.39 1056 165	29 1.61 1123 209	98 5.44 1037 94
	32	23 1.28 1031 183	49 2.72 981 123	46 2.56 860 95	26 1.44 975 122	95 5.28 922 79
8	4	21 1.17 1442 289	51 2.83 1151 176	25 1.39 1251 229	47 2.61 1179 168	76 4.22 1184 140

	8	15 0.83 1295 171	57 3.17 1003 130	34 1.89 1036 125	38 2.11 1084 144	91 5.06 1015 93
	16	17 0.94 1051 203	55 3.06 1020 113	57 3.17 1000 117	15 0.83 989 189	112 6.22 1010 81
	32	22 1.22 1273 423	50 2.78 859 85	59 3.28 850 95	13 0.72 898 310	109 6.06 854 64
16	4	18 1.0 1548 387	54 3.0 1319 198	27 1.5 1257 223	45 2.5 1167 140	81 4.5 1299 151
	8	16 0.89 1379 389	56 3.11 1017 120	52 2.89 1038 140	20 1.11 1206 259	108 6.0 1027 92
	16	14 0.78 1250 261	58 3.22 1028 121	56 3.11 946 84	16 0.89 1261 328	114 6.33 988 74
	32	16 0.89 1634 316	56 3.11 1165 133	63 3.50 1407 257	9 0.5 1289 195	119 6.61 1269 135

32	4	28 1.56 1634 316	44 2.44 1165 133	33 1.83 1407 257	39 2.17 1289 195	77 4.28 1269 135
	8	16 0.89 1197 272	56 3.11 1089 101	58 3.22 1098 102	14 0.78 1237 239	114 6.33 1093 71
	16	20 1.11 1215 267	52 2.89 1014 122	64 3.56 1003 80	8 0.44 1138 360	116 6.44 1008 70
	32	13 0.72 1740 946	59 3.28 915 75	64 3.56 865 60	8 0.44 806 156	123 6.83 889 48

EXPERIMENT VII

Types of event defining target 0 – Appearance X – Disappearance	Misses	Hits	Correct Rejections	False Alarms	Correct Responses
	Max Total		320		640
	Max Mean		16		32
1) 000	29 1.45 1377 252	291 14.55 1044 44	279 13.95 1111 52	41 2.05 1333 140	570 28.5 1077 34
2) XXX	118 5.9 1221 134	202 10.1 1121 61	257 12.85 1045 56	63 3.15 1365 148	459 22.95 1078 41
3) OXO	99 4.95 1377 141	221 11.05 1132 59	184 9.2 1184 62	136 6.8 1233 115	405 20.25 1156 43
4) XOX	110 5.5 1237 102	210 10.5 1130 59	212 10.6 1075 256	108 5.4 1225 116	422 21.1 1102 132
5) OOX	92 4.6 1381 171	228 11.4 1067 50	214 10.7 1157 69	106 5.3 1265 99	442 22.1 1111 42
6) XXO	98 4.9 1250 90	222 11.1 1111 51	210 10.5 1182 82	110 5.5 1372 161	432 21.6 1146 48

APPENDIX 2: MAJOR STATISTICAL ANALYSES

EXPERIMENT I ANOVA Summary

Source:	SS	df	MS	F
Type of event (A)	1.00	1	1.00	4.45
Pattern size (B)	4.93	2	2.47	9.03
No. of dots (C)	19.81	3	6.60	20.44
Subjects (S)	15.12	25	0.60	
A x B	0.58	2	0.29	1.10
B x C	16.41	6	2.74	8.26
A x C	0.97	3	0.32	1.52
A x B x C	2.28	6	0.38	1.90
A x S	5.62	25	0.22	
B x S	13.65	50	0.27	
C x S	22.23	75	0.32	
A x B x S	13.17	50	0.26	
B x C x S	49.67	150	0.33	
A x C x S	15.91	75	0.21	
A x B x C x S	29.97	150	0.20	
Total	211.32			

EXPERIMENT II ANOVA Summary

Source:	SS	df	MS	F
Type of event (A)	2.16	1	2.16	2.30
Pattern size (B)	1.15	1	1.15	2.49
No. of dots (C)	0	1	0	0
Pattern luminance (D)	0.16	1	0.16	0.77
Subjects (S)	23.88	13	1.84	
A x B	3.02	1	3.02	6.99
A x C	0.02	1	0.02	0.04
A x D	0.07	1	0.07	0.22
B x C	0.07	1	0.07	0.26
B x D	0.45	1	0.45	1.57
C x D	0.88	1	0.88	2.28
A x B x C	0.02	1	0.02	0.08
A x B x D	0.29	1	0.29	0.77
A x C x D	0.28	1	0.28	0.72
B x C x D	0.02	1	0.02	0.06
A x B x C x D	0.07	1	0.07	0.32
A x S	12.22	13	0.94	
B x S	5.98	13	0.46	
C x S	4.88	13	0.38	
D x S	2.72	13	0.21	
A x B x S	5.61	13	0.43	
A x C x S	5.86	13	0.45	
A x D x S	4.30	13	0.33	
B x C x S	3.56	13	0.27	
B x D x S	3.68	13	0.28	
C x D x S	5.00	13	0.39	

A x B x C x S	3.12	13	0.24
A x B x D x S	4.84	13	0.37
A x C x D x S	5.09	13	0.39
B x C x D x S	4.12	13	0.32
A x B x C x D x S	3.05	13	0.24
Total	106.50		

EXPERIMENT III ANOVA Summary

Source:	SS	df	MS	F
Type of event (A)	2.37	1	2.37	1.26
Type of pattern (B)	428.01	1	428.01	420.02
ISI (C)	355.16	5	71.03	68.34
Subjects (S)	36.77	17	2.16	
A x B	0.33	1	0.33	0.38
B x C	35.44	5	7.09	7.56
A x C	6.46	5	1.29	1.12
A x B x C	6.11	5	6.11	1.70
A x S	31.96	17	1.88	
B x S	17.32	17	1.02	
C x S	88.34	85	1.04	
A x B x S	15.00	17	0.88	
B x C x S	79.73	85	0.94	
A x C x S	97.73	85	1.15	
A x B x C x S	61.06	85	0.72	
Total	1261.77			

EXPERIMENT IV ANOVA Summary

Source:	SS	df	MS	F
Exposure condition (A)	1569.75	3	523.25	580.40
Subjects (S)	14.42	11	1.31	
A x S	29.75	33	0.90	
Total	1613.92			

EXPERIMENT V ANOVA Summary

Source:	SS	df	MS	F
Exposure condition (A)	288.78	2	144.39	46.53
Displacement (B)	1166.63	4	291.66	113.11
Subjects (S)	95.40	15	6.36	
A x B	48.23	8	6.03	2.59
A x S	93.09	30	3.10	
B x S	154.71	60	2.58	
A x B x S	279.24	120	2.33	
Total	2126.08			

EXPERIMENT VI ANOVA Summary

Source:	SS	df	MS	F
Type of event (A)	124.69	1	124.69	57.59
t1 (B)	418.59	3	139.53	80.60
t2 (C)	171.24	3	57.08	24.28
Subjects (S)	119.62	17	7.04	
A x B	64.76	3	21.59	16.62
B x C	32.33	9	3.59	3.10
A x C	34.22	3	11.41	7.01
A x B x C	19.10	9	2.12	1.87
A x S	36.81	17	2.17	
B x S	88.28	51	1.73	
C x S	119.88	51	2.35	
A x B x S	66.24	51	1.30	
B x C x S	177.55	153	1.16	
A x C x S	83.03	51	1.63	
A x B x C x S	173.15	153	1.13	
Total	1729.49			

EXPERIMENT VII ANOVA Summary

Source:	SS	df	MS	F
Types of event (A)	876.40	5	175.28	23.30
Subjects (S)	553.51	19	29.13	
A x S	714.59	95	7.52	
Total	2144.50			