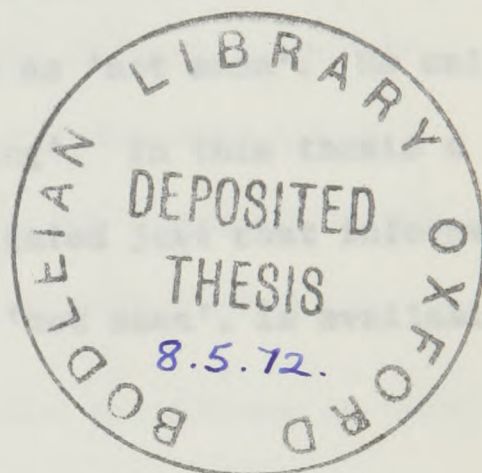


Metaccontrast is the type of visual masking which occurs when the
normal perception of one stimulus, the first stimulus (FS), is disrupted
by a second stimulus, the masking stimulus (MS), presented 10-100 msec
later in time and at an adjacent but not overlapping position. Research
has described metaccontrast in displays consisting of several letters
forming a horizontal row but described very briefly in a scrambled
temporal order. The first few letters presented are followed by adjacent
letters presented later in time and are reported as a single unit.
This metaccontrast phenomenon 'sequential masking' is the subject of this
series of experiments in which the effects of various factors on the
strength of metaccontrast are investigated. These factors are discussed
in the chapters.

**VISUAL PERCEPTION AND METACONTRAST
AT RAPID INPUT RATES**

Geoff D. Cumming
Magdalen College



Thesis submitted for the degree of Doctor of
Philosophy in the University of Oxford.

October, 1971

Department of Experimental Psychology,
South Parks Road,
Oxford.

Abstract

Metacontrast is the type of visual masking which occurs when the normal perception of one stimulus, the test stimulus (TS), is disrupted by a second stimulus, the masking stimulus (MS), presented 50-100 msec later in time and at an adjacent but not overlapping position. Mayzner has described metacontrast in displays consisting of several letters forming a horizontal row but displayed very briefly in a scrambled temporal order: the first few letters presented are enclosed by adjacent letters presented later in time and are reported as 'not seen'. He called this metacontrast phenomenon 'sequential blanking'. In this thesis a series of experiments is reported which investigated just what information about such suppressed letters, those which are 'not seen', is available to the observer.

A review of our present knowledge of masking and metacontrast is given in Chapter 2 and then in the following chapter the observations of Mayzner and his associates are described and their model of visual information processing, based on their work with sequential blanking, is discussed. The model postulates that letters do not reach consciousness ('subjective visual experience', SVE) until at least about 130 msec after presentation and that interactions in that time among the responses of visual analysers determine whether any particular letter will arrive in SVE or will be suppressed. It is suggested in Chapter 3, however, that suppression is not all-or-none and that investigation of the different perceptual analyses required for different responses to suppressed letters, rather than simply asking whether the letters are seen or not, would be valuable.

Chapter 5 describes experiments in which S classified whole displays by making fast keypress responses. The results showed that suppressed letters can be analysed sufficiently quickly and in sufficient detail to control a choice motor response of normal speed and accuracy, even when the analysis had to be sufficiently detailed to distinguish letters and digits.

In the experiments of Chapter 6 S searched through displays of random letters looking for a single target letter and gave keypress responses to indicate whether each display did or did not appear to contain a target. Suppressed targets were usually detected quite efficiently, but if S adopted a strict criterion for target presence it was mainly the suppressed target letters which were missed.

The first two experimental chapters described situations in which suppressed letters were analysed at least almost as efficiently as other letters. In the next, Chapter 7, experiments are described in which S identified letters at various positions in the displays. Suppressed letters were found to be generally difficult to identify. In addition, if position intrusion errors were excluded the remaining errors, item errors, were more likely to be acoustically confusable with the correct letter if the correct letter had been suppressed. This result suggested that suppression is the degradation of visual information in particular and that sometimes S could name the letter before it suffered suppression.

In the experiments described in Chapter 8 a matching task was used. S gave a keypress response signalling either that two successively presented letters were the same or were different, or that two entire displays were the same or were different. Acoustic and visual confusibility was manipulated in the 'different' trials in an attempt to determine whether the memory and matching processes employed depended mainly on acoustic or visual coding. The results suggested once again that suppressed letters are more difficult to process than other letters and that *in some conditions there appears to be a tendency for* acoustic coding ~~was~~ *to be* relatively more important for these letters.

The final experimental chapter, Chapter 9, reports investigations of the appearance of displays. Ss gave ratings of the brightness, apparent duration and perceived clarity of individual letters in metacontrast and control displays. Suppressed letters were judged as appearing less bright and shorter, but no less sharply defined than other letters.

The results were interpreted as showing that suppressed letters are available for processing for a short time before suppression occurs. Metacontrast suppression appears to be a reduction in apparent brightness caused by fairly peripheral neural processes. But whether suppressed letters are reported as 'seen' or not depends on whether an appropriate perceptual analysis can be applied to them sufficiently early and quickly to give a confident categorisation, which can preserve information about them despite suppression of their apparent brightness. For example a letter-digit discrimination can be made sufficiently quickly to trigger a choice motor response of normal speed and accuracy. There is also some

evidence that a word, all of whose letters are suppressed, might even so be identified because wholistic word recognition is so fast. Organisation of the perception of the whole display into a good Gestalt is another way in which information about suppressed letters may be preserved. Analysis of letters before they suffer suppression improves with long practice.

The conclusion that information about suppressed stimuli is available for a short time and then lost unless recoded and stored applies also to standard metacontrast displays, of squares or circles for example. It disagrees with theories that metacontrast consists simply of immediate, irretrievable, partial loss of information. It also suggests that we should not postulate that stimuli either reach SVE and are seen, or are entirely suppressed, but rather we should investigate the time course of the brightness reduction that is metacontrast and investigate the perceptual analyses which allow information about these stimuli to be preserved through suppression.

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Acknowledgements.

I am very grateful to my supervisor, Dr. Anne Treisman, for her good advice and critical reading of a draft of this thesis.

I am grateful also to Dr. P.M.A. Rabbitt for his comments on an earlier report describing several of the experiments. Professor R.N. Haber and other visiting and resident psychologists also gave generously of their time and counsel. S. Fearnley kindly allowed me to use his analysis of variance computer program.

I would like to thank Mrs. A. Briggs for typing the manuscript to a dead-line despite a temperamental typewriter, and J. Broad and C. Blackmore for preparing the figures.

My wife Lindsay has made the whole exercise possible by coping with evening and week-end computer sessions and the resulting irritable spouse. She served as a pilot S on many occasions. More recently, she typed the entire draft of the thesis and lettered all the figures. For all this I am very grateful.

While carrying out this work I was supported by a scholarship from the Rhodes Trust.

G.C.

CHAPTER 1

Overture

Visual masking and metacontrast. Why they are interesting. Why it would be more interesting to use letters and words. Mayzner describes metacontrast masking of letters. The strategy of this thesis.

We see the world in a series of glimpses. Saccadic eye movements occur between glimpses, and a glimpse is typically some 300 msec long.

Considered from above, this organization of input poses questions about how we integrate information obtained during successive fixations. Somehow we manage to do so, and thus build up a percept of a stable world. In the process, we manage to avoid conflict between the very different images formed on the retina during successive fixations. Considering from below this organization of input into glimpses, we can ask what we can see during a single fixation. We can investigate how time, space, energy, contrast and complexity limit the amount we can see during one fixation. A large amount of experimental work has been directed at this last problem and most commonly some form of tachistoscopic presentation is used to ensure that input effectively occurs during just one fixation.

The next stage of complexity involves presenting two successive displays in a tachistoscope and studying how our visual system copes with the double stimulation. If the two displays are sufficiently separate in time, seeing the first will be quite independent from seeing the second. But as the two come closer in time, the two seeing processes may interfere; either one may facilitate, inhibit or completely disrupt the other. Studying the interaction tells us much more about the visual system by showing just how it breaks down when overloaded in various ways. Hopefully, we can in this way learn about the normal input process during a single fixation, and also something about how the visual system avoids clashes between inputs from successive fixations. This interaction of visual inputs, if it is inhibitory, is known as visual masking.

The study of visual masking leads to consideration of many aspects of perception. Conversely, experimental work in many fields of perception turns out to require experiments involving visual masking. So, quite apart from the study of masking in its own right, visual masking experiments have been required in the study of retinal photochemistry, dark and light adaptation, peripheral neural organization, binocular integration, contour and shape perception, movement and apparent movement perception, sensory short-term memory and even word recognition and

reading. With so many issues involved it is scarcely surprising that masking does not turn out to be a single, simple phenomenon. Indeed, it will be a recurrent theme throughout this thesis that many phenomena, involving a variety of stimuli, observers' strategies and response measures are all part of 'visual masking'.

Some definitions are now in order. We shall say that one visual stimulus, the masking stimulus (MS), masks another visual stimulus, the test stimulus (TS), if it interferes with its normal complete perception in any way. Typically MS is larger or brighter or longer-lasting than TS, but it need not be. If MS follows TS in time we have backward masking; if MS arrives first, forward masking. Metacontrast is the name given to masking when MS does not overlap TS in space; usually they have adjacent contours. An important variable in all masking studies is the temporal separation between TS and MS. We shall measure this from the onset of MS to the onset of TS, and refer to it as the stimulus onset asynchrony (SOA). Strictly then negative values of SOA will correspond to backward masking, but it will usually be clear whether TS precedes or follows MS and so the sign will frequently be omitted.

Looking ahead, in Chapter 2 we shall survey some of our present knowledge of visual masking. It will quickly become clear that the usual responses in a masking experiment: 'Yes, it is present on this trial', or 'I can't see it now ... Now I can just see it', may be made to any of several aspects of the display. A single masking curve, a graph of percent detected against SOA, may reflect responses made to different aspects of the display at different SOA values; perhaps temporal flicker, simultaneous brightness contrast, presence of contour, apparent movement, or total duration. Variation of TS and MS along single dimensions (e.g. size, luminance, contrast), the use of various responses by S and phenomenological descriptions can go some way towards untangling the roles in masking of the different aspects of the display. One conclusion is that there is at least some independence in the processing of the various aspects of the visual system. This conclusion comes very conveniently just as the physiologists, with Hubel and Wiesel in the van, are discovering neural structures that fit very well with the notion that information about different aspects of an input is encoded and transmitted by parallel neural channels showing some degree of independence.

But single cell recording techniques cannot be applied to man, so the investigation of man's neural organization must rely on indirect experimental approaches. Masking and, in particular, metacontrast experiments allow the effects of different stimulus attributes to be separated to some extent, and so they offer one possible approach to the study of human neural organization. Indeed, their exploitation in this direction has begun.

Most masking experiments have employed simple stimuli: white flashes of light or simple figures, such as circles, squares or rings. Such stimuli were of course chosen for their simplicity and we still do not completely understand their masking. But looking ahead, it will soon become constricting to work with stimuli having only relatively few separable aspects. The use of more complex stimuli, letters and eventually words, will allow use of all the techniques of search, matching, classification, identification and reading which have been investigated extensively by workers studying more central aspects of human information analysis. In other words masking studies may be able to go on from the study of luminous energy, apparent brightness and simple contour, to the study of more complicated contour, and eventually perhaps to

'letter-ness', 'digit-ness', and meaning. So far masking of character arrays by visual noise-fields has been used to provide controlled presentation of letters and digits for experiments aimed at studying more central information handling. The present line of argument is suggesting that the application may usefully go the other way. We start by knowing something about what kinds of information are needed in a visual display, and for how long, for S to conduct a particular type of analysis on the input. Then, if he can conduct that analysis on letters in a masking display of interacting letters, we know something about what kinds of information survive masking. This approach might show, for example, that masking occurs at several levels in the visual system, or it may show that masking occurs at just one fairly peripheral level, but allow us to study it more completely. The attraction of this line of speculation is, of course, that more complex aspects of stimuli are probably handled more centrally in the nervous system and so analysis of their effects may tell us something about neural organization at this deeper level. So visual masking is interesting, but visual masking of letters may turn out to be even more interesting.

Returning to the present, Mayzner has described conditions which give metacontrast masking of letters by other adjacent but not overlapping letters. He has described numerous effects which may be observed with suitable manipulations of the display arrangements. Letters are presented, but are not seen, then others can be suppressed and the original ones become visible again; letters are seen as displaced from their true positions; shapes and sizes and orientations are found to be critical in determining just which characters are seen in a particular set of conditions; and word recognition may even occur when the letters forming the word are all masked. Considering the preceding argument, these letter masking phenomena are likely to be most illuminating if we study just what aspects of masked letters are suppressed and under what conditions. This approach will require variation of display conditions and, most importantly, variation of S's task and response; the great advantage of working with letters is that a variety of tasks and responses is available which are not available with simpler stimuli.

This is the main line of this thesis: we shall discuss display conditions in which letters are not seen, but then we shall pay most attention to a series of experiments aimed at analysing just what attributes of

masked letters may be extracted from displays when S is given an appropriate task. But before turning to experiments, we shall survey in Chapter 2 the present knowledge of visual masking, and in Chapter 3 we shall discuss Mayzner's demonstrations of the metacontrast masking of letters and shapes.

CHAPTER 2

Visual Masking and Metacontrast

The importance of the observer's criterion in masking. Our present knowledge of masking: masking of flash by flash, masking of shapes by flash, interactions between successive shapes, and metacontrast. The debate about U-shaped curves. Theories of masking and implications for visual processing.

2.1 Approach to Visual Masking

The label 'visual masking' covers many phenomena. This point has been made many times, but still needs to be stressed, for far too many papers still end merely by saying 'it is concluded that at least two distinct processes are involved'. Of course there are; the problem is to distinguish and explain them. Kahneman (1968) made this point about the multiplicity of masking phenomena by listing different limiting cases of masking paradigms. For example: at $SOA = 0$, metacontrast becomes a simultaneous contrast or figure-ground discrimination; or when TS is a form and MS a flash, then with simultaneous presentation, MS merely reduces the contrast for TS. Acting as an observer in masking experiments leads one to a similar conclusion from another direction: all sorts of cues may be used to carry out the required task and the cues used

can vary within an experiment and from time to time with the same display conditions. So when we vary a display parameter (TS luminance, say) we should not infer that a change in the probability of a 'Yes' response is necessarily mediated directly by a change in the corresponding subjective dimension (TS brightness). It may depend on one or many indirect cues and the cues used may change in a complicated way with the display parameters. So masking is many-faced and we will not expect to find one theory handling all of visual masking and also we will expect problems in finding out just what stimulus attributes are controlling S's behaviour.

The simplest way to find out what cues are important is to ask S. But this seems unscientific, and anyway it is hard to know what to do with his answers. Perhaps these reasons account for the omission from many papers of any comments about the appearance of the displays used and the cues which S thought he was responding to, but there is probably a more important one: in many masking situations S can choose for himself a criterion for response which seems natural, and which leads to fairly consistent responding. Subtle changes in the experimental conditions, or the experimenter's instructions might lead S to adopt a different criterion, and different Ss may adopt different criteria in the same conditions, but any

single S often gives stable performance. Masking studies usually involve many hours observation by a very few Ss, with great emphasis on stability and consistency of performance over sessions. Consequently, idiosyncratic criteria may not show up as large individual differences within single studies but undoubtedly contribute to variations across experiments.

Kahneman (1968) introduces the term 'criterion content' to refer to the type of cue used by S for a report. This is contrasted with 'criterion level' which refers to β , the decision theory measure of laxity or stringency, or the response bias adopted by S. Kahneman notes that in many cases subjects can adopt a criterion which shows a fair degree of stability within subjects and agreement across subjects; he calls any such a 'natural criterion'. But he also notes that even a natural criterion can be based on criterion contents which change in a systematic way, with SOA for example, and that study of criterion contents involves phenomenology. Haber (1970) and Neisser (1966) are among those calling for the use of more systematic and detailed phenomenological reports in masking and perception experiments. But then the argument of Garner, Hake and Eriksen (1956) should be recalled: they maintain that there is no need to retreat to regarding private introspections as data, nor to abandon the study of

finally separability of components

the human visual system.

internal constructs, for ingenious manipulation of the stimuli presented and responses required, and the use of converging operations, allow the study of processes between observable input and observable response.

Phenomenological descriptions will guide us in choosing the best experiments, but do not remove the obligation to do them. The use of rating scales is one approach to analysing in detail the effect of particular manipulations of display conditions in masking studies. It has been used to good effect e.g. by Kahneman (1967^b) and Blanc-Garin (1969); Weisstein (1970⁶⁹) has recently elaborated on the usefulness of this technique in the study of metacontrast.

The problem of the responses to be used in studies of masking, and their interpretation, has been raised first because it is central to all that follows. We shall now turn to a survey of some of what is known about visual masking. The field is vast and complicated, with many experiments and issues blurring across any set of classification categories. The arbitrary plan we shall adopt is to start with the interaction of two flashes of light. We shall proceed to the masking of form (e.g. letters or shapes) by a light flash, to the masking of form by form or pattern, and then to metacontrast. Then we shall consider the 'U-shaped curve', discussion of which has generated much heat, and finally separability of attributes and analysers in the human visual system.

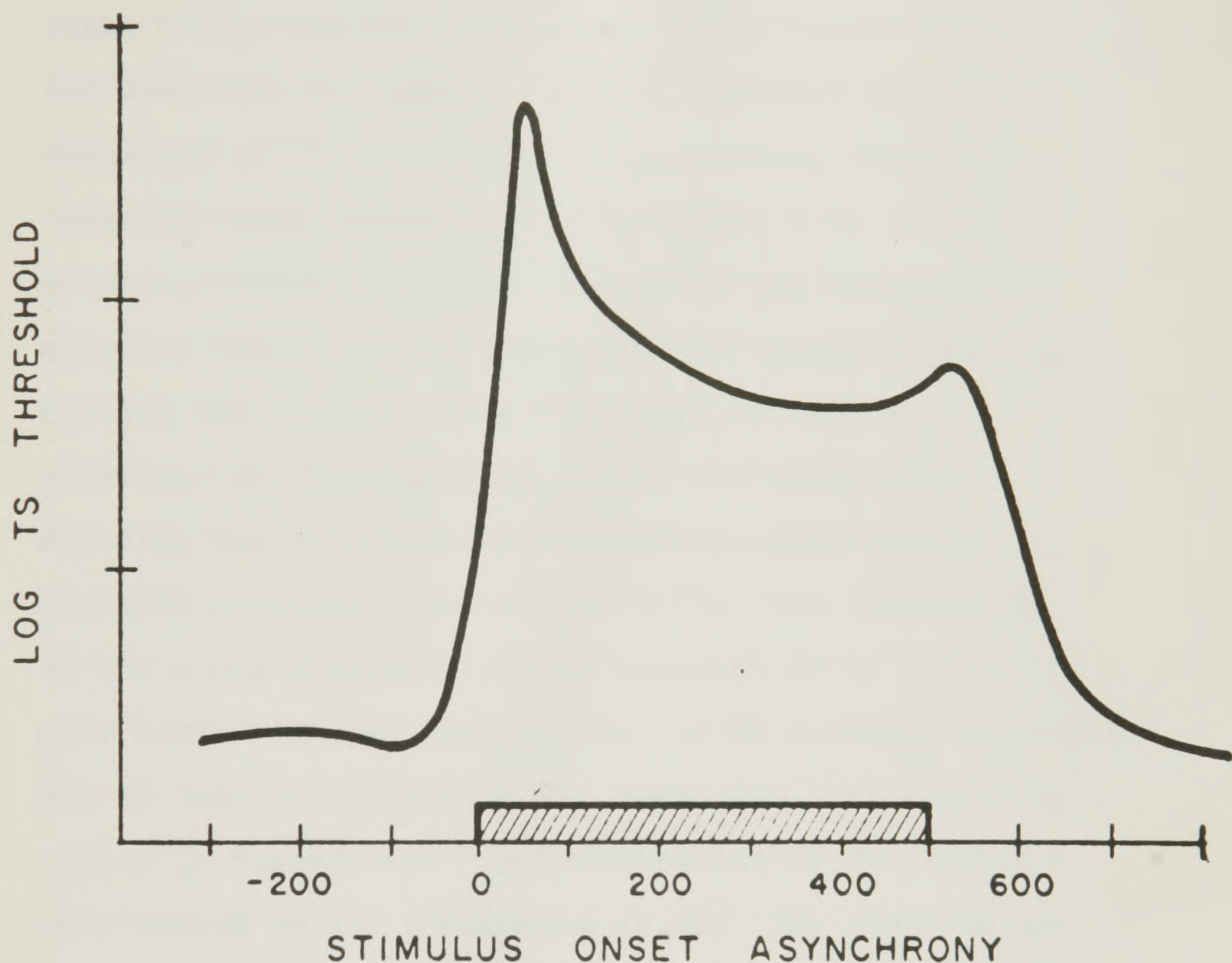


FIG. 1. Schematic masking function. The threshold for detection of a brief TS is plotted against SOA. The duration of MS is 500 milliseconds. Plotted values are characteristic but arbitrary.

(from Kahneman, 1968)

2.2 Masking of flash by flash

If a small, short, dim flash of light (TS) is followed within about 50msec by a large, long, bright flash of light (MS), then TS is not seen, or at least the threshold for detection is raised. If SOA is varied and the threshold of TS determined at each value, then the function shown schematically in Figure 1 is found. Sperling (1965) discussed changes in the criterion contents which seem to determine the threshold at successive SOA values; this is a good example of a situation in which Ss give stable and consistent results, but the criterion content changes systematically with SOA (see Section 2.1). The strange dip in the curve obtained when TS precedes MS by 50 to 100 msec indicates that the presence of MS actually decreases the TS luminance required for detection. At these SOA values Ss report that the presentation of TS results in a change in the appearance of MS. For simultaneous onset of the two flashes, threshold is at its maximum, for S must rely on a simultaneous brightness judgement in detecting TS. When the onset of MS precedes that of TS, however, both spatial and temporal cues may be used, and the threshold is correspondingly lower.

Measurements of the masking of flash by flash have been made in the context of many different experimental and theoretical approaches. Piéron (1925) made his original careful study as part of an investigation of latency differences. He realized, of course, that MS could not act backwards in time, and that any apparently retroactive interaction can take place only if the processing of TS has been delayed for some time. He measured the maximum SOA giving backward masking as a function of the luminance, duration, wavelength, and retinal position of TS. He discussed his results along with other approaches to latency differences: the earlier work using simple reaction time (RT) (e.g. Piéron 1914), and that using the Pulfrich phenomenon (Engelking and Poos, 1924; see also Wilson and Anstis, 1969). Crawford (1947) was the first worker to measure masking for positive (MS onset first) as well as zero and negative values of SOA. He too invoked a transmission time explanation, but wisely left open the question of whether the signal from MS overtakes that from TS on the way to the brain, or whether the interaction occurs more centrally during some 'process of perception' which takes appreciable time.

Reasonably bright flashes, and that the effect was the very lowest luminance flash, it was determined by the luminance of the first few milliseconds of the

It is well established that backward masking varies with TS energy; so does perceptual latency. Roufs (1963; Gibbon and Ritschmann, 1969 obtained similar results) measured the perceptual latency of light flashes as a function of flash luminance, using two perceived simultaneity methods and a motor RT method and found that the methods agreed. Vaughan, Costa and Gilden (1966) found agreement between the changes in latency of the averaged occipital evoked response and those in motor RT as flash luminance varied, thus further establishing the relation between luminance and perceptual latency, and showing that the lag occurred in the retina. The step of directly relating the two lines of work by measuring simple motor RT to the TS, MS combination was not taken until recently (Grossberg, 1970), and turns out to be fairly complex. The problem is that motor RT and the masking of TS have different critical durations (t_c : the longest interval within which flash duration and luminance may be traded reciprocally). Raab, Fehrer, and Hershenson (1961) and Grossberg (1968) found that t_c for motor RT is very short (usually less than 10 msec and less than 1 msec for reasonably bright flashes), and that for all but the very lowest luminance flashes, RT was determined by the luminance of the first few milliseconds of the

flash: further lengthening of the flash duration would not reduce RT. Donchin (1967) found, however, that Bloch's law was more nearly followed for backward masking, although luminance was a little more effective than time. The difference in t_c values implies that motor RT and apparent brightness are determined differently. Matheson (1970) provided further evidence that this is so by showing that with increasing adaptation luminance, brightness of TS decreases, but that motor RT also decreases. So the issue is complicated, but Grossberg (1970) did not make a direct comparison between motor RT and backward masking using the same stimuli; it would be useful to conduct such a study.

A simple perceptual latency hypothesis is not, of course, sufficient on its own, for why then is TS not seen at SOA=0? Some central confusion must be added to the theory, as Cheatham (1952) has pointed out.

Measurements of the masking of flash by flash have also been considered in the context of dark and light adaptation. Baker (1953, 1955, 1963; also Boynton and Miller, 1963) measured TS thresholds near MS onset and offset with adapting fields of various luminances as background. He described the changes in TS threshold

within a few tenths of a second of MS onset and offset as the early parts of the light and dark adaptation curves. He presented evidence that these early parts of the curves represent neural limitations, with photochemical changes limiting response only later in adaptation.

Boynton (1958) argued that the shape of the masking curve (Fig. 1) resembles that of the neural on-response. The arrival of MS sets off a large on-discharge, and the weaker TS cannot break through sufficiently to have its own response detected. If this is so, he reasoned, then raising the preadaptation level would reduce the size of the on-response to the large MS relatively more than that to the small TS and so TS should be more easily seen. Boynton and Kandel (1957) presented a preadapting stimulus, switched it off, presented TS a few hundred milliseconds later, and then presented MS. With this sequence an increase in the preadapting luminance might be expected to raise the TS threshold and does so if MS is not presented. But it also should decrease the on-response to MS and therefore decrease the TS threshold to the extent that neural factors associated with MS onset are responsible for masking. The TS threshold is found to decrease and the size of the change was interpreted as meaning that this masking

is mainly neural in origin. Boynton and Siegfried (1962) and Onley and Boynton (1962) took the on-response argument further and showed that flashes of equal apparent brightness but of different luminance, duration, or energy produce very similar on-responses (possibly after translation of the time axis) as measured by TS threshold change and by an increment threshold technique.

Two flash masking appears to be primarily a neural effect, but where does the interaction occur? Wagman and Battersby (1959), Boynton (1961), Battersby and Wagman (1962) and Battersby and Sturr (1970) concur in finding very little masking with dichoptic presentation of TS and MS (e.g. 0.4 logunit change in TS threshold when a 3 logunit change is observed with monoptic presentation). Also, although variation of MS energy changes the amount of monoptic masking drastically, it makes almost no difference to the amount of dichoptic masking. But the size of the dichoptic effect is disproportionately affected by changes in the areas of TS and MS. So most interaction occurs at a peripheral site, while the very small amount of central interaction seems to depend on spatial or edge properties rather than on energy. This conclusion may be contrasted with the results of experiments using two flashes which were both below absolute threshold, presented to corres-

ponding points of the two eyes. Battersby and Defabough (1969) found that two such 5 msec flashes presented foveally summated if SOA was less than 25 msec, and Martin (1962) found some facilitation for the detection of two 2 msec flashes presented 7° in the periphery, for SOA values up to 100 msec. So the lack of interaction or the slight inhibitory interaction between dichoptically presented flashes is limited to stimuli which would easily be perceived if presented singly.

In most of the studies referred to so far it was not clear what criterion contents Ss were adopting at the various SOA values, although it is a reasonable assumption that simultaneous brightness comparisons account for performance at SOA zero, where masking is maximal. In particular, it is not clear what, if any, use S makes of edge cues. We shall discuss edge and contour effects at length in later sections, but considering only two flash masking it seems that they usually do not play a large part. Dodwell and Standing (1970) used two flashes of precisely the same size and position as TS and MS and obtained typical masking functions. Donchin (1967) on the other hand used a semicircular flash for TS and a much larger circular flash for MS. He required Ss not merely to detect whether TS was present, but to give an eight-alternatives

forced-choice response as to the orientation of TS.

So the task became an acuity judgement, but the masking function was the usual monotonic curve with maximum masking at SOA zero. But if TS and MS edges are close then edge effects may become important, even though TS and MS are still just superimposed flashes of white light. Schiller and Greenfield (1969) masked a 0.25 degree circular TS with a concentric circular MS of varying diameter. For MS diameter 0.32 degrees or greater the usual monotonic masking function was obtained. For MS diameter 0.29 degrees, not only was the amount of masking increased but maximum masking was obtained at SOA of 20 msec rather than at zero; our first encounter with a U-shaped (actually an inverted U-shaped) curve. Such functions are associated with masking which results from contour interactions and Schiller and Greenfield's result shows that edge effects can be important in two flash masking. Sturr and Frunkes (1968) also present data suggesting the importance of edge effects in two flash masking, and they make direct comparisons of masking by flash and masking when TS and MS are black (concentric) circles on a white ground, when contour interactions are certainly important. It would be instructive to measure two flash masking using either flashes with

very blurred edges (Cornsweet, 1970, p. 409) or flashes to the ganzfeld to eliminate edge effects entirely.

There is a small amount of electrophysiological evidence relevant to two flash masking. The explanation for the effect given by Boynton and by Baker (see above) is that the small neural response to TS is simply lost in the larger, longer-lasting response to MS. Schiller (1968), recording from the lateral geniculate nucleus (LGN) in the cat, found that if TS and MS were both within the receptive field of a unit then the response to TS was indeed lost within the response to MS, if SOA was sufficiently small (e.g. less than 50 msec). Sturr and Battersby (1966) obtained similar results and also showed that there is very little interocular interaction at LGN and greater interaction in the cortex for monoptic than dichoptic presentation of TS and MS. Donchin and Lindsley (1965; also reported by Donchin, Wicke and Lindsley, 1963) recorded and averaged the occipital visual evoked response (VER) in man to a semicircular TS masked by a higher luminance, larger, circular MS. They found that for large SOA values (e.g. 250 msec) TS and MS gave independent responses. For SOA values of 75 and 90 msec, S reported that the brightness of TS was enhanced by MS and the joint response was very similar to that obtained by adding the responses ob-

tained previously to TS and MS separately. For SOA less than 50 msec S reported that TS was masked by MS and the joint response no longer resembled the sum of the responses to the separate flashes, but more nearly resembled that to MS alone. Also relevant is the work of Wicke, Donchin and Lindsley (1964) showing that VER shape and latency depend strongly on apparent brightness and change very little if the luminance, duration, area or shape of a stimulus is changed without changing its brightness. It is tempting to conclude that the VER is a measure of brightness and hence of any visual masking which is just a lack of brightness discrimination. But other workers have found a stronger dependence of VER characteristics on shape than on energy (John, Herrington and Sutton, 1967), or on salience or uncertainty-reduction (Sutton 1970a). Sutton (1970b) and Uttal (1965) have discussed at length the many problems associated with inferring relationships between evoked responses and perceived phenomena. Brindley (1970, p.116) is typically forthright in declaring that the sixty or more papers (to 1969) studying the averaged evoked potential to various visual stimuli have added almost nothing to our knowledge of the visual system because the response is too gross and is difficult to relate to perceived phenomena.

There is just one study in the literature in which chronically implanted electrodes in man are used in a study of visual masking and it, alas, is of little value. Galbraith and Heath (1970) had access to an S with temporal lobe epilepsy. They presented a 10 msec circular flash, 5.8 degrees in diameter as TS and a very short, high energy, circular flash, 7.2 degrees in diameter as MS. They recorded from LGN, limbic system and occipital cortex and obtained a pattern of changes with SOA and percent TS detected suggesting that the masking interaction was, at least largely, central. But because they used circular flashes of similar diameters it is not possible to tell whether their masking was limited by brightness or by edge effects. They then stimulated, either in the rostral mesencephalic reticular formation, or in the anteromedial septal nucleus, and observed a slight fall in the proportion of trials on which TS was detected, over a range of SOA values. They interpreted these results as showing that such stimulation affected the masking interaction specifically and as offering further evidence that such interaction occurs in the 'higher visual centres'. But their results could just as reasonably be interpreted by supposing that the stimulation they gave simply changed S's criterion. They gave catch trials, but merely reported that S

almost never gave a false positive response. Since a non-negligible false alarm rate (FAR) is required if sensitivity (d') and criterion level (β) changes are to be distinguished, the data cannot rule out a criterion shift interpretation. Such an interpretation is quite plausible because the stimulation used was felt as 'pleasant' by the S. It is sad that such an elementary fault of experimental design should be made a full ten years after the arrival of decision theory.

Another approach to two flash masking is based on the extensive study of lateral inhibition in the eye of Limulus; see Ratliff, Hartline and Miller (1963) for a summary. As early as 1960, Diamond (1960) applied the concepts of on-responses, off-responses and recurrent, delayed, lateral inhibition to building a model of human brightness perception, with considerable success; see Kornfeld and Lawson (1971) for the latest such model. Ratliff (1965) took the argument further and Cornsweet (1970) used these concepts to describe a number of new illusions. Ratliff (1961) pointed out that such theories make predictions about interactions in time as well as in space, and so became relevant to masking. The main idea is that lateral inhibition spreads the influence of a strong MS into adjacent areas and times and so makes

it harder to perceive a weak TS presented close to MS in space or time. An example of a study in this vein is that of Matthews (1968). He determined the masking curve (as in Figure 1) for a small TS, with a uniform bright field as MS, and again with a field with a sharp contour between black and white regions as MS. The contour changed not only the spatial distribution of masking, but also its time course.

So far we have discussed a number of approaches to masking, without finding a satisfactory overall theory. Latency differences, confusion of neural responses and lateral inhibition give plausible accounts of some of the masking phenomena and are all no doubt involved in the complicated interactions which are masking. Some promising starts have recently been made at integrating these ideas into an overall theory. Sperling's (1965) work on masking used impulse flashes i.e. bursts of light that were effectively instantaneous. Such stimuli are important because knowledge of the response of a linear system to impulse inputs allows calculation of its response to any input. The visual system is definitely non-linear, but even so Sperling and Sondhi (1968) and Sperling (1970) were able to develop an ingenious model of the visual system, based on an electrical circuit made up of several RC stages, with

feedback and feedforward circuits. Martin (1968) described a similar model. These models give good fits not only to the impulse masking data, but also to critical flicker frequency (CFF), increment threshold and critical duration data. Kelly (1969) took a different approach and applied the concept of a modulation transfer function (MTF) to the spatial and temporal properties of the visual system together. Cornsweat (1970) gives an excellent account of MTF ideas in the study of vision. In essence, if the response of a linear system is known for sinusoidal inputs, then Fourier analysis allows calculation of its response to any periodic input. The theory may be applied to input which is periodic in space or in time, or, by suitable convolution of functions, both. Kelly used sinusoidal gratings flickering sinusoidally in time to examine the application of the theory to the visual system. The main problem (Kelly, 1969; 1970) is that the response of the retina is not only nonlinear, but also not time invariant, homogeneous (the same in all places), isotropic (the same in all directions), or achromatic, and in particular it seems that sharp contours in space, and sharp onsets and offsets in time, are particularly important for the visual system. Even so, Kelly (1971) presents an impressive theory of

vision based on first a linear diffusion process (receptors?), then a non-linear inhibiting network (neural feedback at the plexiform layer?). It is comforting still to be able to discern in these models roles for latency differences, neural confusion, and especially lateral inhibition.

In summary, two flash masking seems to occur mainly because of fairly peripheral interaction of neural responses, with latency differences and lateral inhibition in the retina being important. There is only a small amount of inter-ocular masking, and this may depend mainly on edge effects. We now have some promising theories of the visual system which integrate masking results with data from several other types of psychophysical experiment. Finally, even with simple two flash masking, response may be made to various aspects of TS, such as brightness or shape, and it may be possible to analyse the contributions of such aspects.

2.3 Masking of form by flash

If a single black letter of sufficient size and contrast is presented on a white card it is easily seen. If a bright homogeneous white flash is added to the input to the eye (via e.g. a semi-silvered mirror; if

reflected from the same card the contrast is obviously unchanged), then the contrast is reduced and the letter may not be seen. This is masking of form by flash, with SOA zero. Interest in this type of masking has been directed towards the type of interaction occurring between TS and MS, its locus in the visual system, and the inferences which may be made about the contour formation process in perception.

Eriksen has been the most consistent and forceful proponent of the 'luminance summation - contrast reduction' theory of masking. It is certainly true that if a form and white flash are presented simultaneously the uniform light from the flash summates with light from the form to reduce the contrast between the form and its background. The theory postulates that at small non-zero SOA values light from the form and the flash is still summed, and so the contrast of the form is once again reduced. Eriksen and Hoffman (1963), Eriksen and Lappin (1964) and Thompson (1966) presented data supporting the theory; it appears to explain masking of form by flash very well, at least when the pre- and post-fields are dark. In these conditions Eriksen and Lappin (1964) found very nearly symmetric forward and backward masking curves for SOA values up to 100 msec, as would be expected if the visual system simply integrates all input within

an interval longer than the SOA. Eriksen (1966) tested the theory further and found that the symmetry of forward and backward masking does not hold exactly, even with dark pre- and post-fields. Forward masking is found to be greater and Eriksen interprets this by saying that in forward masking TS 'has its contrast impaired right from its initial onset at short inter-stimulus intervals. On the other hand, a form stimulation^m followed by a masking flash has the full period of its duration plus the time of its inter-stimulus interval to act upon the visual system before its contrast is reduced by luminance summation from the masking flash'. This is an important modification to the hypothesis of strict summation within an interval, with order of arrival irrelevant. It leaves the theory saying that a flash arriving before processing of the form is complete can interfere with further processing by reducing the contrast of the form, whether this is still physically present or being held in sensory storage (see Section 2.4).

Two lines of evidence suggest that masking of form by flash is only obtained monoptically. A series of direct comparisons between monoptic and dichoptic presentation (Schiller and Wiener, 1963; Schiller, 1965^b; Smith and Schiller, 1966) showed that very little if any

dichoptic masking, whether backward or forward, is ever obtained using a flash as MS. Keitzman, Boyle and Lindsley (1971) observed very slight backward dichoptic masking in 4 of their 9 ss. The other line of evidence comes from the physiologists. Adkins, Fehmi and Lindsley (1969) taught a visual shape discrimination to monkeys, then masked the shapes with a flash. By varying the SOA for flash presentation and observing the proportion of correct response choices they found a monotonic masking curve, extending to an SOA value of about 50 msec. Fehmi, Adkins and Lindsley (1969) recorded from the optic nerve, LGN, and visual cortex of these monkeys and found that the evoked response disappeared in just those conditions in which the behavioural data showed masking was occurring. The evoked responses disappeared even in the optic nerve and so masking of form by flash is clearly a retinal phenomenon.

Kahneman (1964, 1965, 1966a, 1966b, 1967; Kahneman and Norman 1964; see also Kaswan and Young, 1963) devoted a series of studies to the determination of t_c for form. Typically, S had to name the orientation of a Landolt C, with presentation time, contrast, gap size and pre- and post-field luminances as the independent variables. The critical duration, t_c , was then taken as the longest time

within which presentation time and background luminance could be traded reciprocally without change in S' 's performance. Kahneman found that the t_c depended on the difficulty of the task, and increased with energy, reaching 1000 msec for some observers in some conditions. These results should be contrasted with the known variation of t_c for brightness (in this case t_c is the period over which Bloch's law holds): it decreases from about 100 msec at absolute threshold to no more than 20 msec at bright photopic levels. Two conclusions are important for our consideration of masking: the t_c values for form and for brightness have quite different values and depend in quite different ways on energy, suggesting that contour formation and brightness perception are carried out by separate processes in the visual system. Second, long t_c values are obtained at high energy levels even though small eye movements are bound to occur during the presentation, so contour formation seems to be largely a central process. Kahneman, Norman and Kubovy (1967) found that t_c for form was 160 msec for monocular presentation in some particular conditions, but was 320 msec for successive dichoptic presentation in the same conditions. So the limitation on monocular t_c is not determined centrally, but this result need not invalidate the previous conclusion that the contour formation process itself occurs centrally. 1967, 1968; Kahneman, Norman and Kubovy, 1967; Kahneman

Two more of Kahneman's findings are relevant, and take us back to the luminance summation - contrast reduction theory. First, he had his Ss rate the apparent contrast of a briefly presented Landolt C by matching it with a Landolt C presented for 2 sec. Apparent contrast of the briefly presented form varied linearly with its objective contrast, as expected, except at low luminances, where the apparent contrast of the test form was considerably lower than expected. This was shown to occur because the contour of the test form was important for the contrast judgements, but was not seen clearly at the low luminances. Second, if the test form was preceded by a light field and followed by a dark field, reciprocity might be expected to fail because a short bright presentation of the form would summate more effectively with the light field than would a long dim presentation and so would be harder to see. Departure from reciprocity was indeed obtained in these conditions but to a much greater extent than could be accounted for by luminance summation. Kahneman interpreted this result and some related findings of his as showing that onsets and offsets play an especially important role in perceptual tasks with briefly presented visual stimuli. Hogben (1971) studied the interaction of forward and backward masking and found evidence supporting this view. Recent work by Eriksen's group (Eriksen and Collins, 1967, 1968; Schurman, Eriksen and Rohrbaugh, 1968; Schurman

and Colegate, 1970) used a variety of form detection tasks, and intermittent presentation of the target form. They concluded that onsets and offsets are especially disrupting, that brief dark intervals interfere with summation, and that brief dark intervals may sometimes be themselves considered as stimuli, competing with other stimuli to be perceived. Dainoff and Faber (1967) found that one long presentation of a single letter always gave better recognition scores than several shorter presentations of the same total duration, and made similar conclusions about the importance of dark intervals.

In summary, masking of form by flash occurs, but only monoptically, and it is often useful to think of the flash as decreasing the effective contrast of the form. In addition, a quite different series of experiments has led us to conclusions very similar to some of those of the preceding section: onsets and offsets are special and brightness and form are different and are processed separately, form being built up centrally.

2.4 Masking of form by form

If a test form (TS) and a pattern (MS) are presented simultaneously for a short time, then the test form is, naturally, hard to see. The pattern may be another form or a regular or irregular pattern of lines or dots; in each case it makes TS hard to see, and the extent of the

difficulty will depend on presentation time, contrast and, in particular, the degree of similarity between TS and MS and the amount of spatial overlap of TS by MS. This is the masking of form by form, in the special case when SOA is zero.

What happens when SOA is not zero? There are two main possibilities and these correspond to the confusion and the disruption theories which give the two main theoretical descriptions of this type of masking. The confusion theory holds that presentation of MS before or after TS is similar to the simultaneous case: the visual system integrates the energy and the contours over time and the masking occurs because it is difficult to sort the test form from the resulting montage. Kinsbourne and Warrington (1962a,b) took this view and obtained forward and backward masking functions for the masking of letters by a visual-noise field. The two curves were very similar in shape, although a little more forward than backward masking was obtained. Eriksen has consistently supported the confusion theory, regarding it as an extension of his luminance summation - contrast reduction theory of ~~two flash~~ masking. *of form by flash*
In support of the theory he has shown (Eriksen and Collins, 1967, 1968) that the visual system can combine information presented successively, by presenting two seemingly random dot patterns which, when superimposed, formed a nonsense

syllable. Ss identified the syllable, sometimes even with 100 msec separation between the two component patterns. Eriksen and his associates have also supported the theory with evidence from a large number of studies in which a letter is masked by later presentation of a super-posed ring (e.g. Eriksen and Collins, 1965; Eriksen and Rohrbaugh, 1970). Uttal (1969, 1970a,b,c, 1971a) used a single letter made up of bright dots flashed on a cathode-ray tube as TS. He masked the letter with more bright dots presented at random spatial positions and either spaced regularly in time (e.g. a dot presented every 2 msec), or presented in a burst (up to 100 dots presented within 3 msec). He has used various numbers of dots, forward or backward masking or both, and various intervals between TS and a noise burst. His results agree well with the confusion hypothesis, that the visual system combines together inputs within several tens of milliseconds, and may lose the ability to discriminate a test form in doing so. Just as with the summation theory of two flash masking, the hypothesis needs to be weakened somewhat by supposing not only that summation becomes less complete as TS and MS are separated in time, but also that when TS arrives first, some processing of it alone may be accomplished before MS arrives and overlays the icon of TS.

As we saw in the preceding section, this is an important

weakening of the complete summation hypothesis. It accounts for the frequent finding that forward masking is a little greater than backward (Kinsbourne and Warrington, 1962b; Schiller and Smith, 1965; Schiller, 1966).

One quite reasonable and well-established finding should be mentioned: masking depends on the degree of similarity between the contours of TS and those of MS. The confusibility between the two sets of contours turns out to be more important than simply the amount of contour, for example. Fitzgerald and Kirkham (1966), Parlee (1969), Pollack (1965) and Sekuler (1965), among others, provided relevant data. The result fits well with the confusion theory and emphasizes that in this type of masking contour interactions are important.

The rival explanation for masking of form by form is the disruption theory: at first TS is seen by itself, but then when MS arrives TS is displaced or erased and processing of MS alone occurs. An immediate difficulty is that forward masking occurs at all and that the backward and forward masking curves are frequently (Kinsbourne and Warrington, 1962b; Eriksen, Becker and Hoffman, 1970) but not always (Schiller and Smith, 1965) very similar. It might be possible, however, to explain forward masking by a modified disruption theory by assuming that processing of MS disrupts the processing of TS by delaying it and that TS decays

while it is waiting to be processed. Evidence for the disruption theory will be mentioned below, in the discussion of iconic storage, but the relation between the two theories was elucidated by Scharf and Lefton (1970), Spencer (1969) and Spencer and Shuntich (1970). Their results suggest that a confusion theory is necessary for forward masking and is adequate to explain their data for backward masking out to a mask delay of about 150 msec. At longer mask delays, arrival of MS stops any further processing of TS, whatever the mask energy (in the range investigated). But it is scarcely surprising that a fresh mask over-shadows the montage formed by overlapping the mask and the 150 msec-old icon of TS. The argument of the disruption theorists seems only to be with the strong form of the integration and confusion theory, which maintains that the mask, because of incomplete integration, effectively acts backwards in time and that no processing of TS can occur before the arrival of MS. Having already weakened the confusion theory, the only remaining issue is whether the mask 'actively replaces the earlier stimulus' (Sperling, 1963), or just overlays the fading trace of TS, effectively overpowering it if the trace is weak. This is close to a mere semantic difference, at least until some physiologist can adjudicate. It may be possible, however, that if the disruption theory is correct and

if the sudden onset of MS is important in producing the disruption then experiments using a visual noise MS with a gradual onset would show less masking. The confusion theory predicts no change in the amount of masking and so the experiments might be instructive: the multitude of experiments to date all appear to have used strictly rectangular pulses.

With an eye to later sections, it should be mentioned that all the studies referred to, and many others, concur in finding monotonic masking functions of form by form, with maximum masking always occurring at SOA zero. So masking by form resembles masking by flash in that respect. But it differs from masking by flash in an important way: masking by pattern can be obtained dichoptically. If TS and MS are presented separately to the two eyes, masking is still obtained, indicating that the interaction involved here occurs centrally. Greenspoon and Eriksen (1968) obtained the result and Kinsbourne and Warrington (1962b) found dichoptic masking, both forward and backward, to be equal to monoptic masking. Schiller and Wiener (1963) and Schiller (1965^b) made a direct comparison of masking by pattern with masking by flash: pattern masking was obtained dichoptically, although not quite as strongly as in the monoptic condition, while hardly any dichoptic flash masking was observed. Schiller (1965^b) made the

interesting observation that his Ss improved with practice much more in the pattern masking condition than they did with the flash masks: this is reasonable if central processes are more plastic than peripheral ones.

However, the market for tachistoscopes has flourished not because masking is so absorbingly interesting, but because whichever theory is correct the masking of form by visual noise offers a way of allowing visual information to be available for a controlled time. We shall now consider iconic storage, the visual persistence that makes this possible.

The well known work of Sperling (1960a) and Averbach and Coriell (1961) showed that visual information is held in a sensory store for a short time after its presentation. Three or four letters were read serially from the array. The capacity of the icon (Neisser, 1966) is large, but decay is fast and the rate of decay depends on the display conditions, particularly the luminance of the post-exposure field (Sperling, 1960a, 1963). The results suggest that S reads items out from the icon at a limited rate, but that if a partial report cue arrives before the icon has faded too much, the cued item or items can be selected for read-out and so can be reported. An exception was the experiment of Averbach and Coriell's in which they cued the letter to be reported by overlaying it with a black ring, at some chosen time after array

presentation. The icon, at least for the indicated letter, was destroyed and S could only give a correct report if the letter indicated happened to have been one of the few read out from the icon in the interval between array and marker presentation. It is clear that this line of reasoning leads to support for the disruption theory of masking by form: the ring mask terminates abruptly any processing of the icon of the cued letter.

Sperling (1963) took the argument one step further by following the presentation of an array by presentation of a visual noise field. Plotting the numbers of letters correctly reported against the SOA between array and noise onsets gave a straight line, suggesting that the first three or four letters were read serially from the array at a rate of about 10 msec per letter. Ss reported that the array seemed clearly visible until the noise arrived, completely removing the perception of the letters. These observations led Sperling to postulate also that 'this process is not the passive addition of a new stimulus to the fading trace of its predecessor but the active replacement of an earlier stimulus by a later one'. Sperling (1960b) found evidence supporting this view by presenting in close succession a stimulus and its negative. In many cases only one of the stimuli was seen and so

simple summation did not occur. But in the experiments using visual noise as MS, the noise field was presented continuously for some time, as a post-field for each trial, so it is hardly surprising that it overpowered the fading icon even if there was only overlaying of the old with the new as postulated by the confusion theory.

Many experiments have been aimed at determining the properties of iconic storage. Wickelgren and Whitman (1970) showed that it is a non-associative form of storage: items are stored in a two dimensional array which is not content addressable. Experiments requiring partial report on the basis of properties other than array position generally concur with this result (Sperling, 1960a; Von Wright, 1968; Turvey and Kravetz, 1970). Doost and Turvey (1971) showed that the storage of information in iconic storage does not require cognitive processing capacity and so it is quite different from storage in verbal memory. Turvey (1967) demonstrated that material not read out from the icon and stored more centrally is completely lost once the icon has faded, since no Hebb effect could be found, even after 54 repetitions of the same array. (The Hebb effect is the gradual improvement in performance on an item in a verbal memory task which is observed when that item is presented many times, among other items.)

Eriksen and Steffy (1964) and Mayzner, Abrevaya, Frey, Kaufman and Schoenberg (1964) failed to find evidence that cueing for partial report from the icon could be helpful and they questioned the generality of this form of persistence. Keele and Chase (1967) showed that the display luminance level must be high, as it was for Averbach and Coriell, if an icon is to be formed. If a strong icon is not formed, then a partial report technique cannot be helpful because responding appropriately to the cue takes at least 200 msec (Eriksen and Collins, 1969) and a weak icon might decay in that time.

Several approaches have been taken to determining the duration of the icon. Sperling, and Averbach and Coriell inferred its duration from the performance observed with various cue delays. Mackworth (1962, 1963a, b) varied the type of material to be read from the icon, and found the duration to be constant. Values found are in the range 200 msec to 1.25 sec, with all workers stressing that display conditions affect the duration markedly. Sperling (1967) estimated the duration of the icon when array presentation was followed by visual noise, by having ss adjust the timing of clicks until they were perceived as simultaneous with the onset and the disappearance of the icon. The estimate was close to the objective SOA,

for SOA values up to 150 msec. Neisser (1966, p.35) argued that processing from the icon could continue even after the onset of the mask had been perceived, relying mainly on the implausibility of the fast read-out rate found by Sperling. But these rates can only be maintained for a few items and read-out for these few items may better be considered as proceeding at least partially in parallel (Sperling, 1967), so Neisser's comparison with the much slower verbal reading rate is irrelevant. Besides, it is probably more useful to define the icon as the visual image seen by the S and seen to disappear when the visual noise-field arrives, rather than any more deeply coded information which may still be processed after the arrival of the mask. Haber and his associates (Haber and Standing, 1969; Standing, Haber, Cataldo and Sales, 1969; Haber and Standing, 1970; Haber, 1970) used a variety of methods to estimate the duration of visual persistence, although it is not clear that this is the same thing as the duration of the icon. They found that, for light pre- and post-fields, persistence lengthened the apparent duration of even extremely short presentations to 200 msec, but that when presentation time was itself more than 200 msec, little further persistence was found. Efron (1970) used a temporal matching method to estimate that the duration of the minimum visual percept is in the range 120 to 240 msec.

An important concept which has emerged from work with the icon is that of processing time. If the presentation of an array has more than a certain minimum amount of energy, then the time for which it is displayed does not matter. All that matters is the time from array onset until a noise field, or some other array arrives and terminates the icon of the first: this is the processing time. The concept of processing time has proved to be powerful and useful in the analysis of performance in many different visual tasks such as word recognition (Scharf, Zamansky and Brightbill, 1966) and the recognition of letters presented simultaneously (Smith and Carey, 1966), or successively (Haber and Nathanson, 1969; Sperling, 1971).

An enormous number of studies have used tachistoscopic exposure, with or without noise-field masking, to control processing time. They have investigated a great variety of topics and no attempt will be made here to review the full range. Many have been interested in the possibility that expectancy, word frequency, or even emotional content of the stimuli can affect input to the icon. A case can be made that this is so (Dixon, 1971), although we may more cautiously follow Broadbent (1971, Chapter 6) and leave the issue fairly open. A related question is whether set, or prior knowledge of the stimuli can affect the formation of a percept. There are problems of definition and of

finding acceptable sets of converging operations (Natsoulas, 1967), but most reviewers (Haber, 1966; Egeth, 1967; Gummerman, 1970; Harcum, 1970b) have concluded that little or no effect of set on perception has been demonstrated so far. The point is still, however, contested (Winnick and Daniel, 1970).

Most investigators have made the reasonable working assumption that input to the icon is automatic, parallel, and practically instantaneous, given reasonable lighting and contrast. Interest is then directed to the successive stages^{*} of read-out from the icon into a post-categorical memory, to storage and any further recoding, and finally to overt report. Study of even just the read-out stage has produced a complicated and confused picture of results. It is not just a question of whether read-out of the first few items proceeds serially or in parallel (Sperling, 1967; Estes and Taylor, 1966; Wolford, Wessel and Estes, 1968), but a question of what variables affect the form and rate of read-out. Almost every variable investigated has proved to be involved, from the geometry of the array (Haber and Standing, 1969a; Harcum, 1970a) and symmetry of the item shape (Bryden, 1968), to meaningfulness (Newhart, Merikle and Bryden, 1969) to name only very few.

* Broadbent's (1971) terminology is used unashamedly without explanation or continual reference to the source, because it deserves to have become standard usage in experimental psychology by now.

Rumelhart (1970) brought some order to the findings with a mathematical model of read-out from the icon. His model postulates a probabilistic feature by feature read-out from an exponentially decaying icon with read-out at any time dependent on the clarity of the icon at that moment. The unit of read-out is assumed to be like Selfridge's (1959) features but, wisely, is not specified precisely. When a criterion number (C) of the features for an item have been read out, a category-state for that item is reached e.g. the item may be named and represented in verbal memory. The value of C for an item depends on the nature of the task, being lower for a detection task than for a recall task, for example. Masking by flash is handled by supposing that the usually exponential decay of the icon makes a vertical step downwards when the flash is presented, the size depending on the energy of the flash.

The model is plausible and allows Rumelhart to make good quantitative fits to Sperling's individual and group data for partial and full report, and Estes's data for a detection task.

Just one more topic will be considered in this section and that is the uncanny speed at which we can read. Cattell (1885, 1886) observed that a slightly shorter tachistoscopic exposure was required to recog-

nise a common word than a single letter (especially if this was a grandiose German capital!). This is an unexpected result because recognition of a word presumably requires processing of several rather than just one letter; Cattell attributed it to our greater familiarity with associating a name with a word than a name with a letter. Fraisse (1968, 1969) made a different comparison and found that reading a word is faster than naming the corresponding object. These experiments suggest that a word may somehow be processed, very efficiently, as a unit, rather than having to be constructed laboriously from analyses of lines and curves, or even letters. Broadbent and Gregory (1971) varied independently the frequency of appearance in their experiment of words and their component letters and found that word frequency affected performance more than letter frequency. They concluded that frequency affects pigeon-holing rather than filtering and therefore that words are recognised as units rather than being built up from separately perceived components. Reicher (1968, 1969) conducted an ingenious experiment to compare letter and word processing. He presented a four letter word (e.g. WORD), or a single letter, followed by a visual noise-field in every case. Then he presented two letters (e.g. D and K) and required S to give a forced choice response of which had appeared in the array. In the case of WORD,

a correct response could not have been made simply by seeing other letters, because WORK is also a common word. Reicher found that a shorter exposure was needed for equivalent performance with words than with letters, even when the two types of stimuli were mixed randomly in a list so that S could not know which would come next. Wheeler (1970) gave a good example of experimental method in action by systematically eliminating a number of uninteresting but logically possible explanations of Reicher's results. The preferred conclusion from these results is that words are processed efficiently as units, although a sophisticated guessing explanation (Broadbent, 1971) cannot be ruled out.

In summary, form can mask form through contour interactions and does so centrally. The main theories are those of confusion and of disruption. The confusion theory seems best for forward masking and backward masking with short SOA, while with long SOA it is difficult to distinguish the implications of the two theories. Given sufficient energy and contrast an icon is formed and the icon decays with time or may be destroyed, effectively instantaneously, by superposition of a visual noise-field. The time from array onset to noise onset is the time for which information is available in a visual form: the processing time. The array - mask sequence has been used to study many aspects of visual information processing and one result of this approach is the finding that a whole word can be processed efficiently *as a unit*.

2.5 Metacontrast

If a black disk on a white ground is presented briefly and followed 50 or 100 msec later by a black ring, which would encircle the disk if the two were presented simultaneously, then the disk is not seen. The effect is clear and compelling: the disk is phenomenally absent. But with careful observation and a little practice it is easy to give a forced choice response to distinguish between a ring presented alone and a ring preceded by a disk. Typically, the ring is seen to move or expand a little or flicker in time, or the space inside the ring appears either a little darker or a little brighter than the background field outside the ring. These secondary cues betray the presence of the disk, which is, however, confidently described as being not seen. Obviously, at SOA zero the disk is seen for it fills in the ring to form a larger disk; equally clearly, at very large SOA values the two figures will both be seen. So maximum interaction occurs at a non-zero SOA value and we have a U-shaped masking function. This phenomenon is metacontrast.

Alpern (1952) provided a historical introduction to the study of metacontrast. Classic studies in the field are those of Fry (1934), Werner (1935, 1940), Alpern (1953) and Toch (1956). Fry used an annulus as TS and two more annuli, one fitting just inside TS and the other just outside TS, as MS. He varied the presentation time or luminance

of MS until it matched TS in brightness and obtained a very marked U-function. Werner made a very detailed series of observations, mainly using the disk - ring display described in the preceding paragraph, and requiring Ss to describe what they saw. Toch used a square of light as TS and two adjacent square flashes for MS; his data agree with Werner's in showing U-functions. Alpern masked a rectangular light flash with two adjacent rectangular flashes and also obtained a U-function. He used a brightness matching technique: TS and MS were presented only to the right eye, while a rectangular flash of variable luminance was presented to the left eye so as to appear just above TS. The luminance of this flash was adjusted until it appeared to match TS in brightness. These early workers observed many of the effects and put forward many of the ideas which have turned out to be important in the study of metacontrast and which will be referred to below.

The first important question to consider is that of Ss criterion. In the description above of the appearance of the disk - ring display a distinction was made between seeing a clear disk and making a forced-choice response between presence and absence of the disk. If S simply reports that the disk is not there, we don't know which type of response he is making: we don't know what his criterion content is. Using brightness matching may reduce

the problem, but it still may be difficult to match two stimuli which simply appear very different on other dimensions. Such difficulties are discussed at length by the early workers. Fry's SS found it difficult to make the brightness match because the two stimuli took on different colours. Werner reports that SS were able to enhance or reduce the phenomenon 'intentionally' ... 'by voluntarily evoking a certain attitude in observation, the black disk can be made to vanish within the ring'. Toch even reports that 'the protocols of one observer, who was discarded because he reported the centre square throughout, indicate that his performance was probably due to an analytic set, and an unusually careful fixation'. Other comments about individual differences could easily reflect criterion differences rather than the claimed differences in susceptibility to a perceptual effect.

The description of metacontrast given in the studies being discussed suggest that SS set for themselves fairly strict criteria for the seeing of TS. Also, U-shaped masking functions were obtained. What happens if S must make a forced-choice response? Schiller (1965^a), Schiller and Smith (1966) and Heckermueller and Dember (1965) used the disk - ring sequence and Fehrer and Smith (1962) the three squares display in forced-choice experiments. In each case the finding was clear: when TS and MS are comparable in contrast, luminance and duration, as is

usually the case in metacontrast demonstrations, detection of TS is perfect, but that when TS is made much weaker than MS maximum masking is obtained for SOA zero. That is, the U-function disappears. Also, if negative SOA values are used, somewhat more forward than backward masking is found, whereas with normal metacontrast conditions the early workers reported either no interaction or a very slight effect when MS preceded TS. The forced-choice results resemble those discussed in earlier sections for the other types of masking. These and other results lead to the generalization that U-functions and reports of metacontrast effects are obtained when S' 's criterion level is fairly high and TS and MS are approximately equal in energy.

One important addition must be made to these conditions, and is concerned with contour. In both metacontrast sequences described so far TS and MS would share contours if presented simultaneously. This is important for if the contours of MS are moved away from TS, metacontrast decreases (Alpern, 1953; Alpern and David, 1959). Indeed we saw in Section 2.2 that contour interactions can be sufficient to give a U-function, since Schiller and Greenfield (1969) obtained maximum masking at 25 msec SOA when TS and MS were both 5 msec circular flashes of light, of nearly the same diameter. In this case performance resembled that for metacontrast even though MS overlapped TS in space.

In Section 2.4 we saw that masking of form by form also depends on contour interactions and can be obtained dichoptically. Is metacontrast observed with dichoptic presentation? Werner (1940) and Toch (1956) found dichoptic metacontrast to be very similar to the monoptic effect. Kolars and Rosner (1960) found a clear U-function with a dichoptic disk - ring display. Schiller and Smith (1968) used a brightness rating method and obtained even more metacontrast with dichoptic than monoptic presentation. They suggested that binocular rivalry accounts for the increased dichoptic effect. Alpern (1953) mentioned, without giving any details, that he had failed to find dichoptic metacontrast. This negative result has been explained away as being caused by eye movements (Kolars and Rosner, 1960), the use of highly trained observers (Fehrer and Smith, 1962), or the use of an unreliable adjustment method (Schiller and Smith, 1968). In the monoptic case Alpern presented TS and MS to the right eye and required a brightness match of TS with a comparison flash presented to the left eye. It is possible that for dichoptic presentation he simply transferred TS from the right to the left eye and so the two flashes to be matched for brightness were presented to the same eye, and only ^{MS} ~~TS~~ to the other. But brightness judgments can be made somewhat independently in the two eyes (Asher, 1950) and so it need not be surprising that Alpern's particular conditions failed to reveal a dichoptic effect.

Related to considerations of contour is the issue of similarity of TS and MS. Werner (1935) found that if TS is a short vertical rectangle and MS a pair of similar rectangles, metacontrast is obtained, but that if the height of TS is increased the effect disappears and TS is seen. Toch (1956) reported that if some pattern or design is placed in the three squares, no metacontrast is observed unless precisely the same pattern is placed in all three, in which case TS is not seen. Uttal (1970c) reported similar findings and also found that three triangles, for example, could show metacontrast, even though in this case the contours of TS and MS were not adjacent. The complementary effect, that metacontrast is reduced or is not observed at all when contours or patterns are introduced only into TS was reported by Werner (1935). So similarity of form, as well as adjacency of contour, is important in metacontrast. Unfortunately, reports of such observations are not sufficiently detailed to determine whether the similarity of TS and MS, and the closeness of their contours give the same or different types of metacontrast, or whether either is a special case of the other.

Electrophysiology does not yet have very much to say about metacontrast. Schiller (1968) recorded from LGN in the cat and found that the number of spikes recorded

declined monotonically with decreasing SOA, with a meta-contrast display; there was no sign of a U-function. Schiller and Chorover (1966) failed to detect any changes in the human averaged VER associated with a reduction in brightness caused by metacontrast. Vaughan and Silverstein (1968) found that Schiller and Chorover's result could be explained by stray light. They used a dimly lit field, rather than darkness, as a background and found a decrease in the area under the averaged VER which varied with the depression of rated brightness in a metacontrast display. Recalling the difficulty of interpreting VER results which was mentioned in Section 2.2, great importance should not be attached to this single result.

Turning now to theoretical descriptions of metacontrast, the early simple accounts given by Werner (1935) and Toch (1956) are still appealing despite their lack of great explanatory power. There are two main aspects. First, Werner stresses a localised contour interaction: the inner contour of the ring inhibits the perceptual formation of the edge of the disk, and without an edge the disk cannot be seen. The first point is reasonable in the light of the observed dependence of the effect on contour adjacency, and the second is in line with the neurophysiologist's findings that the nervous system transmits mainly edges and from these percepts must be constructed. Further, ss often

describe TS as appearing just as a shadowy dark area lacking in definition. On the other hand Toch stresses the organisational aspects of perception and describes one relevant demonstration: if TS is not one square but two, the second added just to the left of where the left square of MS will be, then neither square of TS is suppressed, but rather a pair of squares making a smooth quick movement from left to right is seen.

Werner and Toch both noted the similarities between the conditions giving metacontrast and those giving apparent movement. In each case the maximum effect is observed at a small non-zero SOA value, the similarity of the two stimuli is important and the effect may be obtained dichoptically. In each case also, the effects are labile and depend to some extent on the observer's set. Fehrer (1965, 1966) pointed out further parallels and Kahneman (1967^a) made a direct comparison of the apparent motion produced by two squares with the metacontrast produced by three squares of the same type. He obtained very similar functions relating the rated effect to SOA in the two cases. His conclusion was that metacontrast is frustrated or suppressed apparent movement: if apparent movement should be seen in different directions at once, then the conflict is resolved by suppression of the stimulus which should give the motion. That this theory does not have great explanatory power is

scarcely a criticism, for neither do its competitors. But it does not take into account the special role of closely adjacent contours. Also, Higginson (1926) described conditions producing apparent movement in different directions at once. Weisstein and Growney (1969) objected that Kahneman's model is unparsimonious in that it makes no attempt to integrate metacontrast with other types of visual masking. They also made some direct comparisons between apparent movement and metacontrast, varying more parameters than did Kahneman. They found that the two effects behave differently with variation in luminance and visual angle, and so concluded that although the effects are undoubtedly related, neither can explain the other.

The only quantitative model we have of metacontrast is that of Weisstein (1968). She aimed at integrating metacontrast with other types of visual masking and so based her model on the well established lateral inhibition process. Her basic postulate was that excitatory and inhibitory processes develop at different rates and so, given a suitable neural arrangement, the excitation generated by TS may be overtaken and cancelled by inhibition from MS. The model is a simple net of five two-factor neurons, whose behaviour was simulated on an analogue computer. Parameter values were chosen to fit the data of Weisstein and Haber (1965) and then these same values

used in an attempt to fit the data of all those studies in the literature giving appropriate data. The model gave a reasonable fit to the gross aspects of all but one of the 25 metacontrast functions to which it was applied. Considering the great diversity of tasks and conditions represented this is a very remarkable achievement. The next question is whether the model is only a descriptive model, or whether there is any correspondence between its processes and those of the nervous system. Immediate difficulties are that the model only responded to the total energy in the TS area and the MS area of the visual field, whereas contour is also known to be important, and that it required inhibition to develop more quickly than excitation, whereas the usual neurophysiological finding is the reverse (Boynton, 1962). Finally, it might be too constricting to seek a model integrating metacontrast with the rest of visual masking when there are so many differences between the two.

Two final results, which are not handled by any theory, remain to be mentioned. First is the finding of Fehrer and Raab (1962) that the simple RT to the TS-MS display is initiated by the onset of TS. Fehrer and Raab used Toch's three square display and found that as SOA was varied the phenomenal appearance of the centre square varied as would be expected, with maximum suppression for an SOA of 75 msec, while RT remained constant at about 160 msec.

The result is reliable (Schiller and Smith, 1966; Harrison and Fox, 1966). Fehrer and Biederman (1962) even found metacontrast conditions in which SS performed close to the chance level if attempting to detect the presentation of TS, but gave RTs as short as if it were not masked. One other effect of a TS masked by metacontrast was described by Kolers (1963, 1964). If two black disks a little distance apart are briefly flashed with a suitably chosen SOA, smooth apparent motion is seen. If now a ring surrounding the first disk is presented just after this disk is flashed, perception of the first disk is suppressed by metacontrast, but smooth movement is still seen.

In summary, metacontrast is more labile, harder to work with and less well understood than the types of masking discussed previously. It is observed when two stimuli of similar energy, and with some suitable spatial arrangement, are presented with an SOA of 50 to 100 msec. Contour interactions and similarity are both important and the effect may be obtained dichoptically. It is not obtained, however, if a forced-choice response is required. Metacontrast seems to involve the suppression in the nervous system of information about just some aspects of TS.

2.6 U-shaped curves

A big change in the pattern of results shown by a masking experiment can be produced by an apparently small change in the display or in S's task. As we have seen Schiller and Smith (1966) found a U-function when Ss were asked whether they saw TS, but observed much less masking and a monotonic curve if Ss were forced to guess whether TS had been presented. There may be something suspicious about a reported experiment which seems to be the same as one's own but which gives quite different results; the workers cannot be entirely reliable! Neisser (1966) greeted the idea of a U-function with an exclamation mark and one of Eriksen's latest papers is called 'Safari to masking land: a hunt for the elusive U' (Eriksen, Becker and Hoffman, 1970). Sometimes the opinion is implied that forced choice response measures, forcing very low criterion settings, are somehow more healthy and respectable and less mentalistic than the stricter criterion settings associated with subjective report (Cox and Dember, 1970; Sherrick and Dember, 1970a,b). The experiments aimed at finding or not finding U-functions could easily have been included in one or more of the preceding sections, but we shall discuss them here in the context of U-functions and shall find that some useful observations have been made, despite the polemic.

First we shall return to the iconic read-out experiments of Averbach and Coriell (1961) and Averbach and Sperling (1961). If a black ring is used as a partial report cue, the poorest performance is found when SOA is 100 msec. The authors' interpretation was that for SOA zero or small the ring surrounds the chosen letter but still allows it to be read out. At intermediate values of SOA erasure occurs, the ring destroying the icon of the letter, and so performance is very poor. At longer SOA values erasure still occurs when the ring is presented, but there is some chance that the required letter has been read out already and so performance increases to the full report asymptote. Eriksen and Collins (1964) gave an identical interpretation of the ring marker data except that they used a confusion rather than an erasure explanation of how the ring damaged the icon of the cued letter. The data cannot decide between the two explanations (see Section 2.4). The important point is that a U-function is found because the ring acts both as a cue for partial report and as a mask for the chosen letter; the experiment might tell us nothing about metacontrast.

The next step was to use a single letter masked by a ring, with once again a forced-choice identification of the letter as a response. Eriksen and Collins used the letter ensemble A, T and U and obtained a monotonic backward masking function, which they interpreted in terms of their

confusion theory. But Weisstein (1966), for quite different theoretical reasons, used a letter ensemble of O and D and presented 1, 2, 4 or 8 letters in a horizontal line. One letter was masked by presentation of a ring at various SOA values. With more than one letter in the array, masking curves were clearly U-shaped and this result agrees with the comparable Averbach and Coriell (1961) result. The single letter arrays were of two types: the letter could either be in one of 4 positions or in one of 8. Now Eriksen, Collins and Greenspoon (1967) pointed out that Weisstein's zero SOA condition was special since in that case the letter and ring were drawn on the one card and presented for 20 msec, while at all other SOA values the mask was presented for 50 msec. Therefore, better performance at zero SOA was hardly surprising and this point should be omitted from the curves in deciding their shape. Weisstein (1968) accepted the criticism. Returning to Weisstein's (1966) data for single letter arrays and omitting the zero SOA point, the shape of the three relevant curves is ambiguous, while that for a single letter in one of 4 positions, in her Experiment II, shows a clear maximum at an SOA of 50 msec. The experiment reported by Weisstein and Haber (1965) is an exact repetition of this condition, and again gives a clear U-function. Mayzner et al. (1965) repeated the experiment and obtained the same result. Eriksen (Eriksen, Collins and Greenspoon, 1967) suggested that cues, particularly of

apparent movement, peculiar to the letters O and D when masked with a ring may operate differently at different SOA values. That is plausible and could account for the differences between the O, D and the A, T, U experiments (see Stewart and Purcell, 1970 for a direct comparison), but does not detract from the respectability of Weisstein's result. More recently Eriksen, Becker and Hoffman (1970) repeated Weisstein and Haber's (1965) study as exactly as they could and obtained a curve showing constant masking out to SOA 50 msec before declining; the slight U-shape in their data was claimed to be insignificant. Weisstein, Jurkens and Onderisin (1970) clinched the matter by using a Landolt C in one of four orientations as TS and a closely fitting ring with gaps cut in the top, bottom and two sides as MS. Subjects were required to give a forced-choice response as to the orientation of TS. The curve showed a clear maximum at 50 msec SOA.

The preceding series of results suggests that if a discrimination is chosen 'considering metacontrast to be a distortion, fragmentation and dimming' (Weisstein et al, 1970) of TS, then even forced-choice response measures will follow the U-function typical of the time course of metacontrast. We immediately lose any hope of a clear division between masking situations showing the two types of masking curves and so it becomes even more important to

know what S's criterion content and level are in any particular experiment. Also we can agree with Eriksen and Marshall (1969) who criticised procedures, such as the method of limits with a yes/no response used by Kolers (1962), 'where Ss were allowed to adopt their own unassessed and unassessable criterion for report', but must not go further and conclude that only those aspects of masking which can be measured with forced-choice procedures are of interest.

Disinhibition, or the reappearance of TS, is an odd phenomenon in masking and will be mentioned now, because its time course must be a U-function and its study will also depend on good control of S's response strategies. It has been reported in several different situations, but the common feature is that addition of extra stimuli to the display sequence disrupts the interaction of TS and MS and allows TS to be seen even though MS is still present. Schiller and Smith (1966) reported that if their disk - ring sequence was recycled repeatedly, with the two inter-stimulus intervals each 80 msec long, then both figures were seen and they appeared equally bright. Weisstein's (1968) nerve-net model accommodated this result neatly. Robinson (1966, 1968) found that if a 23' circular flash was followed by a 46' flash the first was masked, but that if a third flash 92' in diameter was added, the first flash was more easily seen.

Stewart, Purcell and Dember (1968) reported a similar result with a black disk as TS and Purcell and Dember (1968) sketched an explanation in terms of lateral inhibition. Schurman and Eriksen (1969) did not obtain disinhibition with Robinson's display conditions if a forced-choice response for TS presence was required, although they noted the appearance of many complex subjective effects such as Mach bands and apparent movement. Dember and Purcell (1967), however, did obtain slight disinhibition using an identification response. Their TS was O or D and it was followed by a black disk, then a black ring. Disinhibition effects will be important in forming theories of masking and await thorough study.

The careful and systematic work of Blanc-Garin (1965, 1966, 1967, 1968, 1969; Blanc-Garin, Dubrocard and Harlay, 1970) will serve as a link between the discussion of U-functions in this section and that of separability of attributes in the next. TS was a disk and MS a ring; both black on white and white on black figures were used. First she used single disks as stimuli to establish 9-point rating scales for brightness, apparent duration and sharpness of contour. Having obtained linearity, stability over time and agreement between observers, she had her observers rate these aspects of TS in the masking display. Independent variables were TS diameter, presentation arrangement (monoptic or dichoptic), background luminance (observers could be either dark or

light adapted), duration of TS and MS, and SOA. One excellent aspect of the work was that a full range of SOA values was used so that proactive and retroactive conditions simply formed parts of a single time axis.

One early result was that the pattern of brightness ratings with SOA in the retroactive condition changed smoothly from a U-function to a monotonic function as the duration of MS was increased. Another interesting finding may be seen in her figures displaying the points for every individual brightness rating: there is a slight proactive effect and maximum masking occurs at short negative SOA values (the retroactive condition) but when the averaged brightness rating starts increasing with increasing TS-MS delay it clearly does so because the proportions of high and low ratings change, with very few intermediate ratings being given but many doubtful responses being made. It is as if TS is either seen or not seen on any one trial, with the probability of seeing increasing smoothly beyond the SOA for maximum masking. This is not observed for forward masking, however, intermediate ratings being given in this case.

Blanc-Garin's main conclusions arise from comparisons among the results for the three rating methods. In any one condition the three curves of average rating against SOA value usually differ. Most importantly variations in the

independent variables make different patterns of changes to the three ratings. Brightness is reduced when TS and MS are presented to the same eye and are close in space and time; dichoptic presentation or increased spatial or temporal separation generally reduces the dimming produced by MS. Apparent duration is relatively unaffected by spatial separation or dichoptic presentation. Changes in sharpness of contour generally follow changes in brightness, but increased spatial separation or dichoptic presentation did not restore sharpness of contour as markedly as brightness. Blanc-Garin concluded: 'We may suppose that the various sensory dimensions are mediated by different mechanisms acting at different moments... Brightness seems to be the dimension determined soonest in the visual message, but its coding requires a large amount of time... its coding is partially determined in the peripheral parts of the visual system... Apparent duration ... seems to be defined later, is secondary to brightness and perhaps processed at a higher level... The elaboration of contour appears as a secondary phenomenon slowly built up by means of a lateral inhibition process. Accentuation of contours develops in time and is strengthened at the different stages of data processing. It is a more complex, more costly and more fragile dimension than brightness'.

Finally in this section some recent results of Weisstein's (1971) will be mentioned because they illustrate the application of a line of thinking very similar to Blanc-Garin's. Weisstein reasoned that both brightness and contour interactions have been found to give masking, with brightness interactions only occurring monocularly and contour interactions possibly giving U-functions. Therefore if TS and MS are chosen to allow both brightness and contour interactions, presentation is monoptic and a response measure sensitive to both brightness and contour effects is used, it may be possible to obtain a W-shaped curve. If so, one masking maximum would be at SOA zero and reflect a brightness interaction and the other maximum would reflect a contour interaction. Weisstein found that if TS and MS were circular flashes, MS was a little larger and of rather higher luminance than TS, presentation was monoptic and the response used was a rating of the 'proportion of TS disk remaining', then a W-shaped function was indeed obtained. If presentation was dichoptic, the maximum at SOA zero disappeared, as expected.

In summary, controversy over what conditions give U-functions and over the merits of forced-choice response methods has led to experiments suggesting that the debate is empty. But these experiments do show that it is both necessary and possible to distinguish experimentally the variations in different subjective aspects of stimuli in masking displays.

2.7 Separability of attributes

The idea that information concerning different aspects of input is processed in different ways at different times has been laboured repeatedly in previous sections and we have seen many experimental results supporting its validity. In this section some more experimental results with the same implication will be mentioned, then two lines of recent theoretical and experimental development will be discussed.

Haber and Standing (1968) and Liss (1968) presented arrays of one or more letters and required ss to report as many letters as possible, or to give ratings of the apparent clarity and contrast of the array. The array presentation was degraded either by using a very low luminance and short presentation time, or by following the array with a visual noise-field. When accuracy of letter report was the same in the two cases ratings of clarity and contrast were higher for the masked than for the very brief presentation condition. Also, the two types of measure followed different functions with change in severity of degradation in the two cases. So sharpness of contour may even be partially separated from a shape identification task.

Treisman (1962) studied the appearance of displays giving both stereoscopic depth perception and binocular rivalry. Her results suggested that processing of contour, shape, intensity and colour information may be partially separate. For example in some conditions contour disparity gave depth perception of shapes whose colours were rivalling.

A review of the impairments of visual function produced by missile wounds in the brain of man was given by Teuber, Battersby and Bender (1960). For example they described the fairly regular sequence in which different visual abilities return after temporary total blindness produced by some wounds in the posterior lobes. First there is an undifferentiated sensation of light, later a discrimination can be made between stationary and moving light, then orientation may be seen and blurred contours appear and finally colour perception may return. Without implying gross localisations of the relevant mechanisms, the authors concluded that 'there is a functional hierarchy of different aspects of vision which can be derived from their relative vulnerability to cerebral lesions'.

We shall now consider recent experimental and theoretical work in psychology which has aimed at not only defining the dimensions of perceptual analysis but also the basic units, with some attempt to relate the functional units with hypothesized corresponding neural structures. Sutherland (1959) argued that animals' observed abilities of discrimination, learning and generalisation might most reasonably be explained by a processor having specific mechanisms ('analysers') tuned to respond to a particular type of input. Since then of course single cell recording techniques have been used to find many cells with such

properties in animals. The identification of comparable structures in man's visual system is difficult; Weisstein (1969) reviews the difficulties and the progress which has been made so far.

One basic problem is deciding what criteria should be used for judging when psychophysical findings may be taken as providing satisfactory evidence for specific neural analysing mechanisms. Weisstein argued that compatibility with direct neurophysiological evidence in animals and indirect evidence in man is required, and that the psychophysical changes must occur very specifically to the stimulus attribute varied.

So far, the fading of stabilised retinal images, aftereffects and visual masking have provided the main experimental approaches. Most of the work with stabilised retinal images is poorly quantified and there are problems of establishing the reliability and validity of the reporting procedure which must be used. But Weisstein's main objection is that what we see is the output of, presumably, a complicated hierarchy of analysers, with different properties of the same input being analysed by different parts of the system, and so it is not possible to make convincing inferences from observed deficiencies in the final output of the whole system straight back to the

properties of the analysers early in the system. Similar comments may be made about aftereffect techniques, with a particular difficulty being that of determining not only what analysers remain when a particular set of analysers is adapted out, but also what the properties of the adapted analysers are. For example the McCollough (1965) effect obtained after adaptation to two gratings of different colours and orientation may be explained by cells with dipole receptive fields (Harris and Gibson, 1968) rather than by the adaptation of edge detectors as proposed by McCollough and by Fidell (1970). Nevertheless Sekuler and Pantle (1967) and Pantle and Sekuler (1969) presented evidence for a plausible model of movement aftereffects based on earlier proposals of Barlow and Hill (1963) that direction sensitive cells can be adapted selectively. Later work (Day and Strelow, 1971; Strelow and Day, 1971) is trying to define more precisely the properties of the analysers for motion. Similar discussions have been presented for aftereffects of tilt and curvature (Coltheart, 1971) and for figural aftereffects in general (Sutherland, 1961).

Weisstein smiled most approvingly on visual masking approaches to analyser identification, emphasising the great range of stimulus combinations available and the advantage that the time course of processes involved may be tracked. Houghan and Sekuler (1968) used a masking method to obtain evidence for orientation-specific analysers.

Campbell and his colleagues used converging approaches by measuring masking (Campbell and Kulikowski, 1966), contrast detection threshold (Campbell and Robson, 1968) and averaged VER (Blakemore and Campbell, 1969) to study properties of analysers for orientation and spatial frequency.

Thomas (1970) gave a similar analysis in putting forward a model for the function of analysers in human vision. He stressed the hierarchical nature of analyser organisation and pointed out that different experimental approaches might isolate units at different levels and so give conflicting results. An example of such a conflict is that Dick and Dick (1969) found that processing of line orientation was more primitive than letter processing, in the sense that different presentation times were required for tachistoscopic identification; Eichelman (1968), however, found that the time taken to make physical 'Same' judgments for letters was no longer than that required for line segments in various orientations.

The idea that different mechanisms process different aspects of the total input to the organism has been applied in a general, central way as well as in the fairly simple, physiologically-based way discussed above. All of the work on attention may be considered as aimed at identifying the mechanisms which are most easily separable and studying

how the different mechanisms interfere with one another, or how some may be suppressed to the advantage of others. Treisman (1969) used the term analyser not only for the mechanism selectively tuned to a particular colour, which we know to have a closely associated neural structure, but also for the mechanism responsive to French rather than any other language, which will probably never be closely associated with a particular neural structure.

It is attractive to think of the nervous system as being a large hierarchy of analysers of increasing abstractness as we go deeper into the system: from simple to complex to hyper-complex, in Hubel and Wiesel's terminology. Then the task would be to extend the work on specific peripheral analysers inwards, until all was understood, in flow chart terms at least, if not in physiological terms. But it is not even that simple for, as De Valois (1966) stressed, there is great divergence as well as convergence in the nervous system. There is certainly convergence from the 120 million retinal receptors to the one million optic tract fibres, but input from any tiny area on the retina also has a diverging influence: it contributes to more central signals carrying information about brightness, contour, orientation and movement or, even more centrally, meaning and pleasantness. Analysis of such a system inevitably becomes a problem of determining what the units of independence are at each level

and Garner and Morton (1969) analysed just how tricky a task this is, given that usually we can only observe the input to the system and the output from it. But techniques are available and progress has been made.

It certainly is a complex system which allows us to do the things we can do, yet takes up so more room than that in a human head, and so it should be no surprise that the job of understanding it is turning out to be correspondingly difficult.

CHAPTER 43

Mayzner Describes Sequential Blanking.

A review of the observations and experiments reported by Mayzner and his colleagues describing sequential blanking, and of Mayzner's model of visual processing based on these observations.

3.1 Introduction

In the last five years Mayzner and his colleagues have published many papers describing various perceptual effects observed when letters are presented close together in time and space. The main effects have been termed 'sequential blanking' and 'sequential displacement'. Other observations have been related to apparent movement, form perception and visual masking. In nearly all cases observers' phenomenological descriptions of displays provided the data and Mayzner deliberately postponed detailed psychophysical investigation of a few effects in favour of exploratory observations of a variety of displays.

In this chapter Mayzner's early observations and first theory will be described, then some of his later observations will be mentioned. Finally his latest theoretical ideas and associated observations will be discussed.

3.2 Mayzner's early observations

Mayzner and Tresselt (1966), in a paper entitled 'Studies in sequential perception: looking at one thing but finding another', reported the surprise of their Ss who only saw 7 or 8 letters when 10 letters were presented sequentially at a rapid rate in a horizontal line, but in a random temporal order.

Mayzner, Tresselt and Cohen (1966) and Mayzner, Tresselt, Adrignolo and Cohen (1967) reported more systematic observations, although they say that 'since little previous work was available to provide guide-lines for the present study, a phenomenological and qualitative approach was adopted'. They reported that if the letters of the word CHAIR were presented in a horizontal line in the correct spatial order but in the temporal order 42513 (i.e. first the I in position 4, then the H in position 2, etc.), Ss reported perception depended on the SOA between successive letters. For SOA values from zero to 4 msec the letters were seen as appearing simultaneously. For SOA values of 100 msec or more the letters were all seen and appeared in a clear sequence. But for SOA values of about 40 msec the first two letters presented were not perceived at all and the Ss reported seeing the word C A R, with its letters widely spaced: this phenomenon was termed 'sequential blanking'. If the SOA value was changed

gradually from zero to 100 msec, the three types of perception were observed in succession, each merging smoothly into the next. Sequential blanking was observed with a row of Xs, dashes, random letters or letters forming a word. Variation of letter presentation time from 0.1 msec to 50 msec, while holding SOA constant, made little difference. The effect was invariant with changes in viewing distance from a few inches to a few feet, with changes in character size from 0.25 in. to 1.0 in., with a change from head-on viewing to oblique viewing, and with large changes in room illumination. Use of crossed polaroids to present the blanked letters to one eye and the others to the other eye showed the effect to be central. Displays of various sizes and composition and numerous different temporal display orders were used. The general conclusion was that the first 50% or so of letters in a display were not seen, providing that the SOA was chosen so that the duration of the whole display was about 200 msec. Thus the best SOA for a five letter display was 40 msec while for a twenty letter display it was 10 msec. A letter was less likely to be blanked if it was at either end of a display and the other requirement for the observation of sequential blanking was that the temporal display order was scrambled; if it was too regular then the

effect was not observed. For example the orders 123456789t ('t' stands for ten) and t987654321 gave strong impressions of apparent movement. Similarly, for 135792468t two streams of apparent movement from left to right were seen, but once again all letters were visible: there was no sequential blanking. With this display order, incidentally, a large spatial gap was seen between the letters ^{presented} 2nd and 9th; this effect was termed 'sequential displacement'.

The requirements of a scrambled temporal display order and an SOA value giving a total display duration of 200 msec, together with examination of just which letters suffer blanking in particular displays, led to the conclusion that letters which are followed on one or, usually, both sides by other letters arriving about 100 msec later are the ones which are not seen. In large and complex displays 2, 3, or even 4 adjacent letters may be blanked, but similar conditions hold when this occurs. This conclusion fits well with classical findings in masking and metacontrast and Kahneman (1968) in his review includes sequential blanking simply as a special type of metacontrast.

Mayzner noted the close relationship between sequential blanking and apparent movement. A change merely in the temporal order of display, with SOA and other parameters held constant, from a regular to a scrambled

order produced a change from the perception of all letters and strong apparent motion to perception of only some of the letters with perhaps still a little app^aarent movement remaining. Kahneman (1968) made much of this relationship in developing his argument that metacontrast is the suppression occurring when a display gives apparent motion in two conflicting directions at once.

So far sequential blanking has been described as all-or-none, and this is exactly how Mayzner described it. Any letter is either perceived clearly or not perceived at all, and Mayzner stressed the striking and compelling nature of the effect, the excellent agreement among observers and the persistence of the effect even after prolonged observation. In the early papers there is only one slight qualification made: 'only if an observer fixates directly on the location of a missing element and so tunnels his vision as to exclude almost all other elements can a missing element be detected'.

Mayzner, Tresselt and Helfer (1967a,b) described several more properties of sequential blanking. The effect was observed for vertical and oblique lines of letters and it also occurred in two-dimensional arrays of letters, with very similar principles governing which letters or columns of letters were not seen. The effect was not observed when the spacing between letters was

increased to two or three letter widths. And, most interestingly, it mattered whether all the characters in the display were the same. For example if ten dashes or ten strokes were displayed in the order 7 5 9 2 1 + 4 3 8 6 the characters in the underlined positions were not seen, but if the display used was - / - / / - / / - - or / - / - - / - - / / all characters were seen.

As before sequential blanking was described as an all-or-none effect. Mayzner, Tresselt and Helfer (1967a) included a photograph of a simulation of the effect, in which blanked letters were simply omitted from the display 'to show the reader how the display actually appears to an observer when the appropriate input rate is actually employed'. Mayzner, Tresselt and Helfer (1967b) displayed C A R immediately below the sequential blanking display of CHAIR described earlier, so that the apparent and physical absence of the H and I could be compared directly. They say that 'such a comparison produces a visual experience in which Ss report that the two display sequences appear almost exactly alike, but that there is occasionally a fleeting impression that the sequence actually displaying the H and I seems to have a very dim blueⁿ of diffuse light in the H and I locations'.

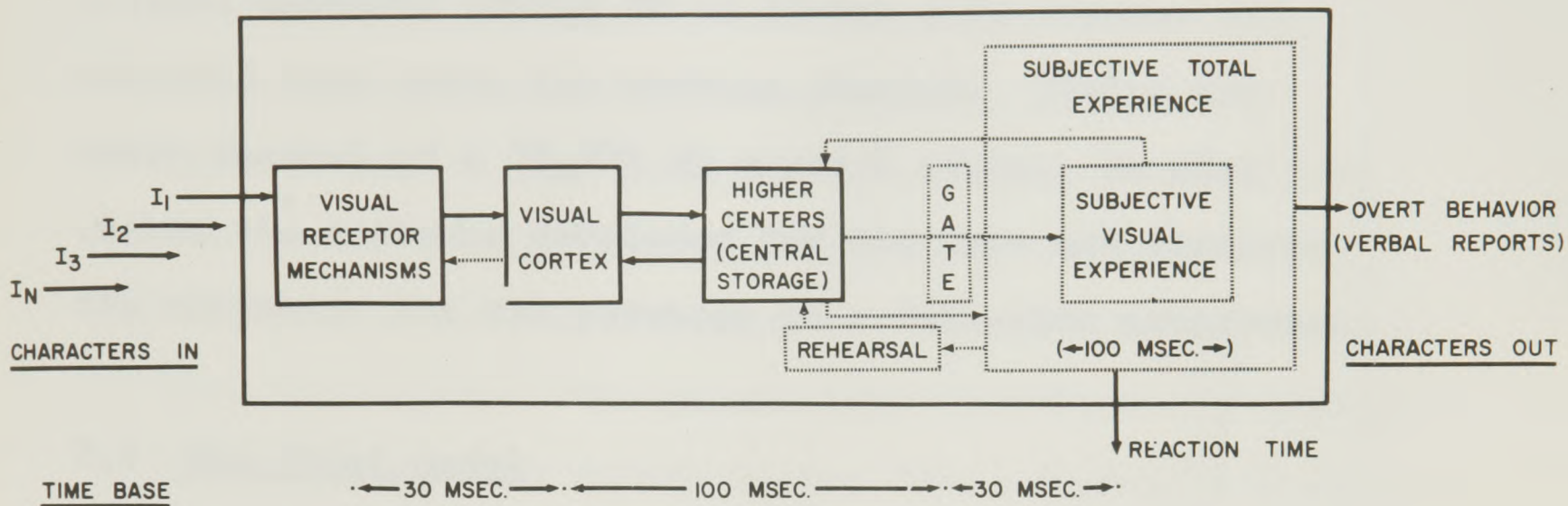


Figure 2. Mayzner's model of the visual information processing system (from Mayzner and Tresselt, 1970).

In two further papers Mayzner (1968; Mayzner, Tresselt and Helfer, 1967a) described the \$200,000 worth of equipment used to present the displays studied. They were presented on one of the four cathode ray tubes driven by a PDP-7 computer having 8K of 18-bit core storage and magnetic tape units for backing storage. Timing was under control of a 20,000 Hz crystal clock. He also described the software developed for the work and stressed the necessity for the services of a full-time programmer.

3.3 The first model

Mayzner, Tresselt and Helfer (1967b) described a model of visual information processing; the model is shown in Figure 2. Impulses aroused by visual stimuli pass up the visual system, beyond the visual cortex and not until about 130 msec after stimulus presentation do they arrive at the SVE (subjective visual experience) box. At the entrance to SVE is a gate which allows signals from stimuli separated in time to interact and which sometimes allows later signals to block the entrance to SVE of earlier signals, thus producing sequential blanking. Verbal report is assumed to reflect the SVE: 'in response to the question, 'What characters do you see in the display?' ... we assume that an observer is reporting his own immediate subjective visual experience (SVE) of what he has just observed and recalls of that observation'.

Mayzner argued that SVE only follows after 100 msec or more of visual processing because it is implausible to suppose that a character enters SVE immediately after presentation, and so by definition is 'seen', only to be displaced 100 msec later by a similar character arriving at the correct time and place to give blanking. He recognised that verbal response is inevitably delayed a little and so a rehearsal loop bypassing the gate was provided to allow S to remember his perception long enough to give his report. The possibility that blanking operates by interference with memory rather than original perception was not considered.

Mayzner discussed whether the gate blocks completely the passage of some inputs or whether some inputs 'are so attenuated in intensity that their perception relative to the much brighter ^{un-}blanked inputs does not occur'. He did not decide between these alternatives although he leant somewhat to the severe attenuation postulate on the grounds that in some cases Ss report seeing some trace of blanked items.

This early model postulated that input takes some 130 msec to reach SVE and so may be interfered with by later inputs, but it did not tackle the problem of how the later input, or some aspect of it, jumps ahead through the visual

processing preceding SVE in order to be able to affect the perception of the first input. Another difficulty is that the estimates of the processing times associated with each box in the model depend heavily on the assumption that a simple visual reaction, taking over 160 msec, requires that a signal reaches and passes through SVE. But Fehrer and Raab's (1962) TS did not reach SVE yet the visual reaction time was still about 160 msec. Mayzner accommodates this by noting that Fehrer and Raab's SS 'may not subjectively experience the target stimulus, [but] they do report a subjective experience of movement, and we would suggest that this movement perception serves as the initiating signal for RT response'. This movement perception, however, is a property of TS and MS together and so can hardly trigger a simple reaction as early as the onset of TS. Also, Mayzner's argument will not explain the result of Fehrer and Biederman (1962) that a normal visual reaction may be elicited by a TS which cannot be detected even by secondary cues.

SVE is the crucial stage of Mayzner's model, yet cannot be defined beyond naming it or taking it as being equivalent to the answer to the question put to the S 'What did you see?'. The whole argument of Chapter 2 that an understanding of masking will only follow experimental analysis using many different tasks is relevant here.

It suggests that experiments using responses other than phenomenal description are required if we are to develop a theory of sequential blanking which is more than a theory of what observers say they saw.

3.4 Further observations by Mayzner

The SVE box in the model (see Figure 2) is shown, tentatively, as lasting for some 100 msec. Tresselt and Mayzner (1969) examined this point further by simply presenting two adjacent or superimposed Xs successively and asking S at what temporal separation the display 'represented a discontinuous visual experience rather than a continuous visual experience'. Values obtained ranged from 60 to 120 msec and were compared with other measures of visual persistence made with quite different displays in quite different conditions e.g. those of Haber and Standing (1969).

Another line of enquiry was concerned with the effect of similarity between blanked and blanking characters. Mayzner, Tresselt and Helfer (1967b) described the appearance of - / - / / - / / - - with temporal order 75921t4386: no blanking was seen. But if the vertical expansion control of the display tube was turned the slashes became shorter and eventually were indistinguishable from dashes, in which case sequential blanking operated and the first five characters (which had been the slashes) were not seen. If the control was turned slowly back again 'as soon as the /s

are again changed in orientation to a slight degree, all five /s reappear on the display'. Once again description was in terms of blanking as an all-or-none phenomenon.

Buchsbaum and Mayzner (1969) studied blanking displays of five vertical lines. With an SOA of 40 msec and with temporal order 31425 ss reported seeing 3 of the 5 lines; the first two presented were blanked. But if the two lines presented first were made either shorter or longer than the other three they became progressively more visible as the length difference increased. Mayzner and Tresselt (1969) obtained similar results using squares as stimuli: if the blanked squares were distorted slightly by changing the length of one of their sides they became visible and the proportion of occasions on which blanking occurred decreased as the amount of distortion increased. The authors interpreted the results in terms of interactions among geometric analysers which are very form specific.

Mayzner, Tresselt and Helfer (1967b) first reported disinhibition in sequential blanking displays. They used an SOA of 20 msec and interleaved the letters of two five-letter words ('beach' and 'carry') to give CBAERARCYH as the display. The temporal order was 61728394t5 and, as expected, ss reported seeing CARRY but not BEACH. If now a third word was added with its letters adjacent to those

of the second word, CARRY (and therefore overlaying some of the letters of the first word, but appearing much later in time) Ss usually reported seeing the first and third but not the second word presented. If a fourth was added, only the second and fourth were seen; the first and third were not seen. Mayzner (1970) reported a similar finding of disinhibition using single letters, not overlaid at any point, rather than words. These findings are similar to those discussed above (see Section 2.6) and also lend themselves to an explanation based on lateral inhibition ideas; Mayzner (1970) gave a description in such terms.

Following up the idea that blanking is produced by interactions among form specific analysers, Schoenberg, Katz and Mayzner (1970) investigated a sequential blanking display consisting of a row of five dots. Under the appropriate conditions only three of the five dots were seen, but if the two blanked dots were moved very far above or below the line all five dots became visible. The authors varied systematically the positions of the blanked dots and so mapped the field of masking influence of the three fixed dots. They tentatively identified this with the shape of an inhibitory field in the human visual system.

Tresselt, Mayzner, Schoenberg and Waxman (1970) reported a further phenomenon. They used a standard blanking display of e.g. BBBBBB with an SOA of 40 msec and a letter presentation time of 20 msec. As expected only three letters were seen. They then noted that if e.g. an N and a B were presented in the same place, each for 20 msec and in immediate succession S saw only an uninterpretable jumble. They combined the two conditions by presenting an N immediately before the presentation of each of the two blanked letters in the BBBBBB display, in the same spatial position as the blanked letters. Ss were required to identify the letter~~s~~ or letters presented in spatial positions 2 and 4, the blanked positions. In the control condition the three non-blanked letters were not the same as either of the two letters overlayed in the blanked positions and Ss made 11% of correct identifications. In the experimental condition they made 37% of correct identifications. The difference is highly significant and was interpreted as showing that the sequential blanking type of interaction can be very specific: later letters can subtract identical letters from the earlier jumble, thus allowing the other letter in the jumble to be seen more easily. This result is strong evidence in favour of Mayzner's idea that interactions among form specific analysers underlie sequential blanking. It would still

be desirable to show, however, that similar disinhibition is not produced by adjacent letters presented simultaneously with the overlaid pair, possibly by some different comparison or subtraction process, but is specific to displays having the time characteristics giving sequential blanking. Robinson (1971) reviewed the studies finding disinhibition in backward masking displays and concluded that if two flash stimuli are presented successively to one eye and then a third, larger flash to the other eye disinhibition is not obtained, even though weak interocular masking of the second flash by the third is observed. So Mayzner's observation should be repeated with the letter pairs presented to one eye and the blanking letters in positions 1, 3 and 5 to the other to confirm that the disinhibition interaction does occur interocularly and so is related to sequential blanking.

Andreassi, Mayzner, Beyda and Waxman (1970) took sequential blanking into the U-shaped curve arena (see Section 2.6). They used the standard five letter blanking display and required Ss to identify the letter presented in spatial positions 2 and 4 i.e. the blanked positions. They varied SOA, incidentally completely confounding brightness with SOA, and obtained a clear U-function with the minimum at an SOA of 40 msec.

The last two experiments are important because they required ss to give a forced-choice letter identification response, rather than to report, as in all previous experiments, how many letters they saw. The earlier experiments raise questions about just what criteria ss adopted for 'seeing' letters, how these criteria varied within and across ss, the effect of the instructions from the experimenter and the demand characteristics of the whole experiment. Much more knowledge than is available about the precise instructions given to ss and examination of the raw responses are required before an attempt can be made to answer these questions. The authors continually stress the striking nature of the effects and say that agreement among observers is very high. The paper by Mayzner (1970) is, however, one of the very few to give data for individual ss. For a control condition very similar to the standard five letter blanking display each s was required 'to fill in the appropriate cells of a matrix, in which he had observed alphabetic characters'. The percentages of blanked letters reported 'seen' by the 10 ss were: 10, 2, 0, 82, 8, 28, 10, 18, 38 and 28, and so agreement among ss was not very good. Once again we feel the need for experiments using various responses and with clear control over response criteria.

The final point to be mentioned in this section is the failure of Eriksen and Spencer (1968) to observe sequential blanking. They could present letters at any of ten positions forming a circle and found that even when they used the time values and display orders reported by Mayzner as optimal neither they nor their Ss could observe sequential blanking. The explanation of this result presumably lies in the different spacing and shape of the displays used in this experiment.

3.5 Later theory

Mayzner and Tresselt (1970^a) summarised many of the observations of blanking and related effects and combined their later ideas of interacting analysers with their earlier model of visual information processing. They were more concerned with events occurring between input and the entry to SVE, particularly at the gate, than they had been in the previous discussion which dwelt on the properties of SVE (see Section 3.3). They postulated 'that the final visual experience is a resultant of certain excitatory and inhibitory processes associated with each input and all other inputs associated 'closely' with it, in space and time.'. 'Thus, if the excitatory and inhibitory fields of a string of inputs begin to overlap, interactions will develop and sequential blanking

and displacement effects may occur.' 'If we finally assume that as a result of about the first 100 or 130 msec of input processing, inputs are 'routed' to locations within this columnar system [as described by Hubel and Wiesel], and that if the inputs arrive in the same column, because of sufficient geometric similarities along dimensions such as line length or orientation, angle size, degree of curvature, and so on, then these inputs may fall sufficiently close to one another for inhibitory fields to interact and so produce sequential blanking effects.' Considering in more detail the interactions required to give blanking they said 'the inhibitory fields of the later inputs are now much stronger than the excitatory fields of the earlier inputs, which are slowly decaying with time; thus inhibitory interactions occur at the gate and the excitatory fields associated with the earlier arriving inputs become greatly attenuated by the inhibitory fields associated ~~with the earlier arriving inputs become~~ ~~greatly attenuated by the inhibitory fields associated~~ with the later arriving inputs'.

This analysis implicitly assumes that inhibition from later inputs travels ahead to interact with excitation from earlier inputs and so it resembles Weisstein's (1968) model and shares with it the problem that inhibition is

usually found to develop and spread more slowly than excitation (see Section 2.5). A less important point is that if the excitation from an earlier input is assumed to have decayed substantially by the time it reaches the gate then it is surprising that we ever see anything at all, for the input then has not yet reached SVE! But the assumption is not crucial to the model.

The authors made much of the effect of similarity between blanked and blanking characters in their analysis in terms of analysers postulated to be very form-specific. The theory thus explains why ///// shows blanking while /-/-/ does not, but only at the cost of not explaining why e.g. CHAIR does show blanking. There are one or two suggestions that homogeneous displays (XXXXX) give 'stronger' blanking than heterogeneous ones (CHAIR), but once again without more quantitative and better defined ways of assessing blanking we can take the argument no further.

The finding of blanking and disinhibition when the letters of 2, 3 or 4 five-letter words are presented in sequence and adjacent or overlapping in space was mentioned in the previous section. This finding was only reported informally on the basis of phenomenological descriptions given by an unstated number of observers and in terms such as 'observers usually report seeing only'. No

description of the instructions to Ss was given. Even so, if interactions do indeed occur over the long time intervals involved in the four word display (some 400 msec), it is very hard to maintain that all interactions among inputs occur before any input arrives at SVE. It would seem more plausible to look for interactions at later stages in processing, and to analyse where interactions occur in terms of a sequence of boxes corresponding to various responses rather than just the single box, SVE, corresponding to the response, 'I see it'. An additional possibility is that memory of the perception of items may be disrupted if they cannot be distinguished sufficiently well from the later items, as may be the case for similar letters presented in a tight jumble in time and space. The interactions between fields which produce the suppression may then be considered to act fairly late in item processing and storage. This line of argument emphasises the importance of the organisation imposed on a display by S and his recoding of items for storage and so comes close to many of the considerations of the previous chapter.

Mayzner and Tresselt (1970^d) reported one further very interesting finding. If SOMERSAULT was presented in the temporal order 1 6 2 7 3 8 4 9 5 t with an SOA of 20 msec, letters in the underlined positions were not seen. Similarly, if MHBOLUXSUE was presented in the same conditions

the first five random letters were not seen but the second five letters, forming the word HOUSE, were seen. But if two common five letter words were interleaved and TCAHBALIER was presented Ss reported the first word presented, TABLE, on 87% of occasions and the second word, CHAIR, on 91% of occasions. (This result is at variance with an earlier informal observation by Mayzner, Tresselt and Helfer (1967b) which was discounted by Mayzner and Tresselt (1970^a.) By comparison Ss never reported seeing a whole ten-letter word and for the displays consisting of five random letters and one word, the word was identified on 88% of occasions, while the five letters were identified correctly only on 21, 6, 4, 8 and 12% of occasions respectively. The authors concluded that word meaning can affect processing before entry to SVE and so can influence whether sequential blanking occurs or not. 'In sum, the sequential blanking paradigm may allow for a spatial mapping of inputs, in the visual cortex and higher centers, differing not only along geometric dimensions, but along 'meaning' dimensions as well'. Uttal (1971b), in a theoretical paper presenting the view that much present theorising and speculation in psychology goes much too far beyond the physiological findings on which it is allegedly based, argues that it is highly implausible that 'meaning', a complex, deep, abstracted property, affects the operation of lateral inhibition and similar processes in the fairly peripheral

columnar structures postulated by Mayzner as the site of the sequential blanking interaction.

There are at least two other possible explanations of this result. The less interesting is simply that Ss could combine scanty information about the five letters forming the first five-letter word and, knowing that a very common five-letter word had been presented, make a good guess. If the two five-letter words forming the display were always close associates, as are TABLE and CHAIR, the only example of the words used given in the paper, then S's task was even easier. No mention of any control of word frequency is made but the two examples given of ten-letter words used are SOMERSAULT and EXPERIMENT and these are both considerably less frequent than TABLE and CHAIR. So it might be reasonable that Ss could guess the five-letter but not the ten-letter words and so this explanation cannot be ruled out.

The more interesting possibility is that since reading a word is a particularly fast process (see Section 2.4), Ss could identify the first word presented and store the word in time to escape the disruption produced by the second word. So in a sense meaning would determine whether blanking occurred, but indirectly by providing S with a way of recoding input to survive

blanking rather than by taking part directly in the interactions which are blanking.

The use of words in such experiments promises to provide some interesting experimental work. Pollack (1971) seems to be the only study coming close to providing relevant observations. He studied word recognition when letter presentation was in a scrambled order, but his letters were spaced one and a half letter widths apart and so it is not surprising that he did not report finding sequential blanking.

3.6 Conclusions

Mayzner and his colleagues have described a variety of very interesting visual effects. In most cases they have relied on ss' phenomenological descriptions of displays and have been content to say 'as the research program progresses, precise psychophysical procedures will be employed to systematically study the findings reported to date, but in no case are these more precise procedures expected to alter in any significant way the results already obtained' (Mayzner, Tresselt and Helfer 1967b). In many cases we have missed the provision of complete descriptions of the experimental task and the instructions to ss and in one case where responses for individuals were published the agreement among ss was not

particularly close. In one case (Andreassi, Mayzner, Beyda and Waxman, 1970) where a forced-choice identification response was required Ss scored 70% correct in one set of conditions giving optimal blanking and this result is certainly different from the 'no letter seen there' phenomenological report elicited by the same displays. So not only may the response of giving a phenomenological report be unstable and hard to control, but other responses may tap other stages and aspects of visual processing.

We can conclude from Mayzner's observations that sequential blanking occurs when characters are presented in a scrambled order and that the characters which are blanked are those having adjacent letters presented about 80-120 msec later. Blanking is not seen if the display order is easily organised into sequences: apparent movement is seen instead. Similarity of shape between blanked and blanking characters enhances blanking, but the effect also occurs for random letters and for letters forming a word. Disinhibition is observed with either letters or whole words, and the interaction appears to be sufficiently shape-specific to 'subtract' a letter from a jumble of two letters and thus allow the other letter in the jumble to be seen more easily. Finally, words can be seen more easily than random letters in some sequential blanking conditions.

Mayzner's theory of visual processing postulates complicated interactions among excitatory and inhibitory signals arising from successive visual inputs. These interactions occur before the items reach SVE and they determine which of any set of input items will eventually enter SVE and so be seen. The importance of interactions among signals from analysers in the visual system is plausible, but the restriction that all interactions occur before SVE is less so. It is probably more fruitful to think of different responses tapping different stages in the visual processing of items rather than one final 'perception' box, SVE, through which all items must pass if they are to influence the response. So an investigation of sequential blanking using various response measures might be fruitful and it is to this that we shall shortly turn.

CHAPTER 4

Sequential Blanking Observed.

The equipment and programs used in the experimental work. Some general aspects of the experiments. Sequential blanking displays are presented: the phenomenon does indeed exist.

4.1 Introduction

This chapter introduces the experiments to be reported in succeeding chapters by describing the computer programs, computer and other apparatus used in the experiments. Then some general features of the experimental procedure are described. Finally, conditions are described in which sequential blanking has been observed. This course is taken in an attempt to establish convincingly that the metacontrast suppression of letters by other letters does indeed occur, however slippery a concept it may become later in the experimental investigation.

4.2 Apparatus

A LINC-8 computer was available to run the experiments. It is a basic LINC-8 machine with 3,000 12-bit words of core memory available for LINC language programming. It has two magnetic tape units for backing store, an on-line teletypewriter and contact-closure inputs, but no clock.

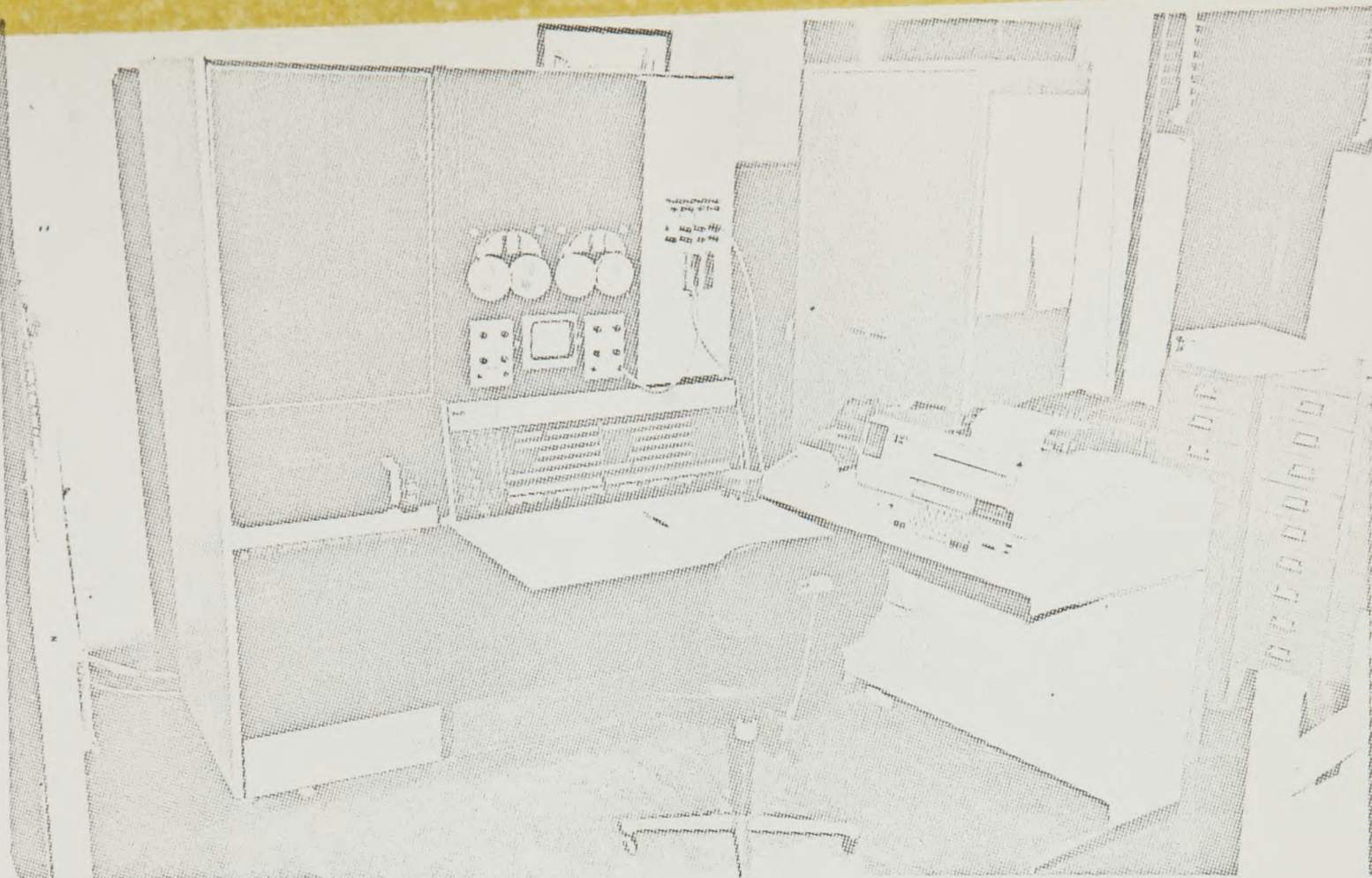


Figure 3. The LINC-8 computer and teletypewriter.

The S's cubicle is just to the left.



Figure 4. S's working position. Note the slave scope with grey surround, the two dim lights, the rubber face mask and the response keys.

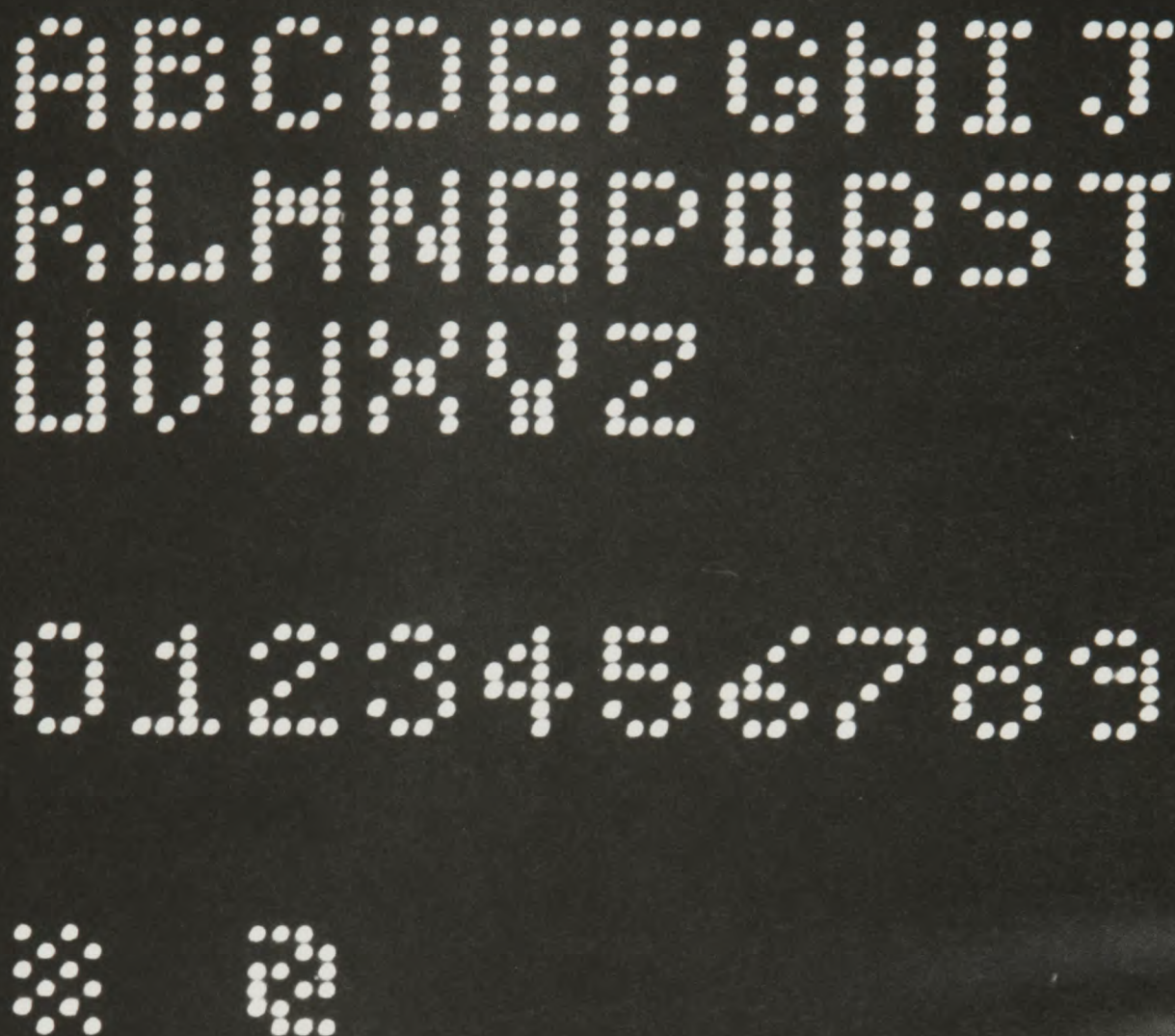


Figure 5. The characters as they appeared on the scope. The figure on the left in the bottom line is the checker-board grid used in Experiments IV and Xe and that on the right is the nonsense form used in Experiment XI.

Figure 3 shows the computer and teletypewriter. An 11 cm by 9 cm cathode ray tube, Tektronix 561 A/RM modified, is fitted as a slave to the master scope of the computer. The slave scope is fitted with P15 phosphor whose light output is rated as decaying to 0.1% within 50 μ sec of the end of excitation. For our purposes therefore any spot forming part of a display on the slave scope may be considered to have no persistence after its excitation by the electron beam. Characters on the slave scope appear bright and slightly greenish against a dim dark-green background. The luminance of the characters is difficult to measure and could not be maintained precisely constant during the 18 months of running experiments, but is of the order of 0.5 log ft-L for characters displayed continuously by the display programs used in the experiments.

The display system includes a hardware character display generator which allows any subset of a 6 by 4 matrix of dots to be displayed efficiently. The patterns of dots selected to form the upper case characters and the digits are shown in Figure 5. Characters are 4 mm high and 3 mm wide and there is 1 mm of space between adjacent characters.

In Experiments II, VI and IX S rested his face against a rubber mask and viewed the scope through a light-tight tube so that the bright display was observed in an otherwise dark field. Viewing was binocular and the viewing

distance was 30 cm so that individual characters subtended 0.8 deg. by 0.6 deg. at the eye and the rectangular area in which a row of 5 characters appeared was 0.8 deg. high by 3.8 deg. wide. In all other experiments S's head position was again stabilized by a rubber mask but the scope was seen in the centre of a dark grey cardboard screen uniformly and dimly lit by two small bulbs placed behind diffusers one on each side of S's head. The luminance of the screen was $-2 \log \text{ ft-L}$. The lighting was arranged so that S's face was in darkness and no reflections could be seen in the scope; reflections, if present, are not only distracting but also lead S to converge and focus behind rather than at the face of the scope. Viewing was binocular and the viewing distance was 35 cm so that individual characters subtended 0.7 deg. by 0.5 deg. at the eye. Figure 4 shows the viewing arrangements.

Two response keys were used in many experiments. They were positioned for easy use by S's two index fingers and were connected to contact closure inputs so that the computer could measure response times (RTs) and record keypress responses automatically.

TSCOPE is a set of LINC-language programs developed to allow the presentation and control of experiments requiring the display of only small numbers of characters at once, but requiring great flexibility in displaying

these few characters. Complete descriptions of TSCOPE and its component programs were given by Cumming (1969, 1971). The system essentially consists of nine related programs held on tape and one master program which is permanently in core. The master program calls wanted programs from tape, maintains display parameter values for use by all other programs and holds reference tables. Ancillary programs permit the automatic generation of certain types of lists of displays, the typing in, editing and storage on tape of any lists of displays, some analysis and output of results, and various other operations some of which will be mentioned in later chapters. LINC-language programs were also written to translate data into a form suitable for analysis by FORTRAN programs.

TSCOPE may be used to control experiments in two main ways. Displays may be triggered one at a time by S using a hand or foot switch, with written response, or the S may be required to give a keypress response and the next display follow automatically after the response.

Timing presented a programming problem because the computer was not fitted with a clock until more than two years after its installation. So TSCOPE relies on memory cycle timing, with all the routines used for displaying,

and recording responses and RTs, being precisely time-balanced, whatever characters are being displayed. The basis for this timing is the computer memory cycle time of $1.5 \mu\text{sec}$; this was measured and found to be accurate in absolute value and stable over time. The display programming is based on a display cycle of precisely 3.405 msec within which up to nine characters are displayed. This is TSCOPE's finest unit of time resolution and all display times, waiting times and RTs are measured in units of display cycles. For example a character displayed for 20 msec would actually be displayed six times, in six successive display cycles.

4.3 The experiments

Some general aspects of the experiments will be described here to reduce the amount of repetition in the descriptions to follow of the individual experiments. The general plan is that in each of the next five chapters several experiments aimed at investigating one particular aspect of metacontrast in displays of letters will be described. The order in which the experiments are numbered and described was adopted as being logical for presentation of the argument, but the chronological order in which the experiments were conducted is approximately: VI, IX, II, VII, VIII, III, XI, I, IV, X, XIII, XII, V, XIV.

In all experiments the Ss were volunteer Oxford students of a young adult age without gross visual defects. Corrective spectacles were worn if prescribed. The proportions of men and women were approximately equal. Ss were paid an hourly wage and in some cases a performance bonus as well. Unless otherwise mentioned Ss were initially naive to the phenomena under investigation and served in only one experiment. When Ss were required for more than one session in an experiment successive sessions were always run on different days. Sessions usually lasted about 50 to 65 minutes.

The usual procedure in an experimental session was for the experimenter to point out relevant aspects of the apparatus, adjust the height of the chair so that S's face was positioned comfortably in the rubber mask and make sure that S understood how to make the required responses. The experimental instructions were read out and any questions answered. Then S was shown a display on the scope of all the characters he would see in the experiment and allowed time to study them. Then the practice lists were given. Short breaks were given between experimental lists and time was allowed at the start of each list for S to adapt to the moderately dim viewing conditions.

There was a five-letter display with the temporal order 42513

(i.e. 51), with each letter being displayed for 20 msec

and with an SOA of 40 msec, produced sequential blankings

In describing the experiments a 'display' will refer to a small set of characters presented close together in space and time. Unless stated otherwise a display consists of five characters presented in a horizontal row in the centre of the scope. One or very occasionally two displays and the associated response make a 'trial'. The displays required for a sequence of from 50 to 200 trials make a 'list'. Lists for an experiment were always prepared and stored on magnetic tape beforehand and then read into memory for use in an experimental session when required.

Four temporal display orders for five-letter displays are used in many of the experiments and will be given abbreviations. The two orders showing metacontrast are bl ('blanking') and blr ('blanking, reversed'). bl is the order 42513 and blr is its mirror image, 31524. Two additional orders are nb ('non-blanking'; 14532) and nbr ('non-blanking, reversed'; 23541). A fifth abbreviation, sm, will be used occasionally to indicate simultaneous presentation of all the letters in the display.

4.4 Sequential blanking observed

Mayzner reported in several papers (see Chapter 3) that a five-letter display with the temporal order 42513 (i.e. bl), with each letter being displayed for 20 msec and with an SOA of 40 msec, produces sequential blanking:

the first two letters displayed, those in positions 2 and 4, are not seen. If exactly the same conditions are used for a display on the slave scope to the LINC-8 then exactly the same observation is made: only three letters are seen. A little apparent movement is seen and with steady fixation on one of the blanked positions some trace of the letter presented there can be detected, but whether the display consists of five identical letters, five random letters, or a five-letter word, striking metacontrast suppression is indeed observed. If the display is recycled e.g. every 500 msec, then the effect is seen to persist and remain compelling. Use of the blr order gives identical observations.

The preceding descriptions have been given spontaneously by ss in many of the experiments and by many informal observers including more or less notable visiting psychologists being shown around the laboratory at various times during the last two years.

Many of Mayzner's other observations have been confirmed informally. For example changes in viewing distance, viewing angle, background luminance and ^{the presentation time of individual letters} ~~display duration~~ have little effect, but the amount of suppression is reduced if SOA is increased or decreased or if the letters are spaced further apart.

The appearance of nb and nbr displays cannot be described so unambiguously. The aim in selecting these orders was to find display conditions 'similar' to bl and blr but not giving suppression and the orders chosen were considered the best rather than ideal. Observers report seeing jerky apparent movement mainly towards the centre in the nb and nbr displays. They often underestimate the number of letters in the display, yet can see each individual letter and report no letter as apparently missing and no apparently unfilled spaces. So the marked suppression observed in bl and blr displays does not occur in these displays.

3.1 Introduction

The simplest task which can be applied to a display is that it should release a simple motor response. Sayers and Jack (1967) showed that TV in a non-motor display can indeed do this. For bl and blr displays the advantage that the suppressed characters are presented first in time and so have the first opportunity to release a simple response. Experiments 1 and 2 showed a simple response to bl and blr displays is indeed released by the first suppressed character.

CHAPTER 5

Simple and Choice Response Times to Suppressed Characters

Expt I Suppressed characters can trigger a simple response.

Expt II Suppressed characters can trigger a choice response when display conditions are constant within a list.

Expt III Ditto, when display conditions are mixed within lists.

Expt IV The result does not depend upon contributions from later characters.

Expt V Suppression by metacontrast is not equivalent to a physical decrease in intensity.

5.1 Introduction

The simplest task which can be required of a stimulus is that it should release a simple motor response. Fehrer and Raab (1962) showed that TS in a metacontrast display can indeed do this. Now pl and plx displays have the advantage that the suppressed characters are presented first in time and so have the first opportunity to release a simple response. Experiment I asks whether a simple response to such displays is indeed elicited by the first suppressed character.

More complex perceptual analysis of a stimulus is required for it to control a choice response. Experiments II, III, and IV enquire whether suppressed characters can be analysed in sufficient detail to do this.

Finally in this Chapter, Experiment V examines a related side issue. We know that RTs to stimuli of low intensity are long. Also, observers report that some letters in bl displays appear absent or very dim. Will a direct comparison show then that metacontrast suppression resembles simple physical dimming at least in its effect on choice RTs?

5.2 Simple responses

Experiment I : Simple Response Times

Ss in this experiment gave simple keypress responses as quickly as possible to the onsets of successive displays in a list.

METHOD

Twelve experimental lists of 170 displays each and 2 practice lists of 50 displays each were prepared. The ensemble of characters used was (ABCDEFGHI 123456789) and half of the lists consisted of pure displays (77777 or BBBB) and half the lists were mixed displays (CDIFA or 36287). Four of each type of list were termed pure lists

because display conditions were homogeneous through the list. One consisted of a random mixture of 85 bl displays and 85 blr displays, each display consisting of 5 letters or digits, and was called the bl(5) list. A second list, the bl(4) list, was formed similarly except that the character presented first in time in each display was omitted, leaving every display consisting of 4 digits or letters. The bl(3) list was similar except that each display consisted of only 3 letters or digits, those presented first and second in time having been omitted. The fourth list in each case was termed the mv(4) (mv for 'movement') list and consisted of displays of 4 letters or digits presented in the temporal order -1234 (mv) or 4321- (mvr), where dash stands for a blank. The first character presented in these displays is thus in the same position on the scope as the first character presented in displays in the bl(5) and bl(4) lists, but no suppression occurs and apparent movement is seen. The final two lists of each type were termed mixed lists because they consisted of mixtures of equal numbers of bl(3), blr(3), bl(4), blr(4), bl(5) and blr(5) displays.

Four Ss each served for 2 sessions. One of the original Ss could not follow instructions and made very frequent anticipatory responses; her data were discarded and she was replaced. In one session S worked through the 6 lists

consisting of pure displays and in the other the 6 lists consisting of mixed displays. The order of presentation of display type was counterbalanced over Ss. In each session the 4 pure lists were presented first, in an order counterbalanced over Ss and sessions, and then the two mixed lists were presented. Ss were instructed to maintain fixation in the centre of the scope and to respond as quickly as possible while making very few anticipatory responses.

The index finger of the dominant hand was used for response. The value of SOA was 40 msec and characters were presented for 20 msec. The time from one response until the onset of the next display, the R-S interval, varied randomly among 8 values ranging uniformly from 1.25 to 1.75 sec. It was necessary to vary the R-S interval since this was effectively the foreperiod and a simple RT task with a fixed, fairly short foreperiod becomes merely a time estimation task and Ss make many anticipatory responses.

RESULTS AND DISCUSSION

The first two responses in each list were considered to be for warm-up and were omitted from the analyses. RT was measured from the onset of the first character to appear on the screen. RTs of less than 100 msec or more

than 800 msec were excluded and then RTs more than 3 standard deviations away from the mean of the remainder were also excluded. 3.2% of all responses were excluded in these ways.

Means of the remaining RTs were calculated for each S for each condition and were subjected to two analyses of variance. Analysis 1 was a 5-way analysis and the factors were: pure/mixed lists; Ss; pure/mixed displays; 3/4/5 characters per display; bl/blr display order. This analysis thus included all the data except that for the mv(4) lists. All main effects and interactions were tested against their interaction with Ss. (This will be the case in all analyses unless otherwise stated.) No interactions were significant ($p > 0.10$) and no main effects were significant ($p > 0.25$) except that the main effect of 3/4/5 characters just reached significance at the 0.05 level. The mean RTs were 229.3, 234.6 and 233.8 msec for displays containing 3, 4 and 5 characters respectively. Individual comparisons among means (Hays, 1963, Chapter 14) showed that the values for 4 and 5 character displays did not differ ($p > 0.10$) but that the value for 3 characters displays is less than the other two values ($p < 0.025$). This 4.9 msec difference is much less than the SOA of 40 msec and so does not alter the main conclusion which must be that the first characters presented in bl(4) and

bl(5) displays, the suppressed characters, do trigger a normal simple response. This result is as expected considering the literature (see Section 2.5).

The explanation for the small difference observed may be that the initiation of response may very occasionally have been postponed until the end of the display, perhaps because of a lapse in concentration, with the result that the bl(3) displays, having a shorter total display duration, would show a shorter mean RT. Examination of the RT distributions might settle the point, but more data than are available here would be required.

Displays of different total durations were deliberately used so that equality of RTs over conditions could not be ascribed merely to the triggering of response by display offset, but would indicate that responses were indeed triggered by display onset.

Analysis 2 was a 4-way analysis including only the results for the pure lists. Factors were: Ss; pure/mixed displays; bl(3)/bl(4)/bl(5)/mv(4) list type; bl/blr, etc. display order. No main effect was significant ($p > 0.10$) and no interaction was significant ($p > 0.05$). The best comparison to make to see whether the RT to suppressed characters is quite normal is that of the mv(4) with the bl(4) condition, because both types

of display start in spatial positions 2 or 4, both consist of 4 characters and so have equal total durations, and while the first character in the bl(4) displays is clearly suppressed that in the mv(4) displays is not. The mean RTs are 232.5 and 236.0 msec for the mv(4) and bl(4) conditions respectively. The difference is not significant ($p > 0.25$) and the 95% confidence interval for the difference is 3.5 ± 7.5 msec.

This experiment indicates clearly that suppressed characters can elicit a normal simple response, and that this is true for both pure and mixed displays and whether or not different display types are mixed in a list.

5.3 Choice Responses

Experiment II : Choice Responses with Display Conditions

Grouped

Ss classified displays into two classes in this experiment, while working under Speed and Accuracy pay-offs. Displays in some lists were Os or Xs and in other lists were digits or letters. Displays were sm or bl and the two types were presented in separate lists.

To the extent that bl RTs were found to be longer than sm RTs, information from suppressed characters was not

available to influence the choice response. Any effect might depend on, among other things, level of practice, the extent to which S was forced to respond quickly and the complexity of the perceptual analysis required. Any influence of level of practice was not investigated in this experiment, but the Speed and Accuracy conditions and the O/X and digit/letter conditions were included to see whether the last two variables mentioned did have any marked effects.

METHOD

Eight experimental lists of 202 displays and two practice lists of 50 displays were prepared. All displays consisted of five occurrences of a single character. In half the lists the character was either O or X, so every display was either 00000 or XXXXX, and these two displays occurred randomly and equally frequently. In the other lists the character was a digit (1, 2, 3, 4, 5, 6, 7, 8 or 9) or a letter (A, B, C, D, E, F, G, H or I), so typical displays were 33333 and HHHHH.

Characters were always displayed for 20 msec and the SOA value was zero to give sm displays, or 40 msec to give bl displays, but was always constant for all displays in a list. The R-S interval was 1.0 sec.

Eight Ss each served in two sessions, one with Speed and one with Accuracy pay-off conditions. In each session four experimental lists were used, one in each of the combinations of O/X and digit/letter displays with sm and bl presentation conditions. The order of sessions was counter-balanced over Ss and the orders of use of lists and presentation of different display conditions were counter-balanced over sessions and Ss.

S was instructed to fixate in the centre of the screen and to press one of the two keys as quickly and as accurately as possible to signal his classification of each display as consisting of Os or Xs in O/X lists, or of digits or letters in digit/letter lists.

To induce a set for speed or accuracy the following instructions were read at the start of the session:

Please try to work as quickly and accurately as you can. Number of errors and reaction time are both used in calculating your bonus payments. But in this session accuracy (speed) will be weighted much more heavily than speed (accuracy). So please try to work accurately (quickly), even at the expense of speed (making some errors).

S was reminded frequently during the session of the emphasis on speed or accuracy and at the end of each list one of the TSCOPE programs was used to calculate, using parameters favouring speed or accuracy as required, the number of bonus pence earned by S's performance on that list.

RESULTS AND DISCUSSION

The first two responses in each list and the single response immediately following any error were omitted from the analysis. (Responses immediately following an error were omitted because such responses are atypical; the point is discussed in Chapter 6.) The mean correct RT and the percentage of errors were calculated for each list for every S. Too few errors were made to permit analysis of error RTs.

Two analyses of variance were performed. The first was a 4-way analysis of mean correct RTs and the factors were: Ss; Speed/Accuracy; O-X/digit-letter; sm/bl. It showed that Speed RTs were lower than Accuracy RTs ($p < 0.025$) and that O/X RTs were lower than digit/letter RTs ($p < 0.001$), but that there was no sm/bl main effect ($F(1,7) = 1.00, p > 0.25$). No interaction was significant ($p > 0.25$).

The second analysis was similar to the first and was applied to the arcsine transform of the percentages of errors. It showed that more errors were made in the Speed than in the Accuracy condition but that no other main effect and no interaction was significant ($p > 0.10$).

Tables 1 and 2 show the mean correct RTs and percentages of errors averaged over Ss, but for the 8 conditions separately. bl RTs appear a little longer than sm RTs in the O/X conditions, but the difference is not significant. Also, if mean bl and sm RTs are compared within Ss for each combination of Speed/Accuracy and O-X/digit-letter conditions the difference is in one direction for 4 or 5 Ss and in the other for the remaining 4 or 3 Ss. So bl and sm RTs apparently do not differ in any condition. But making this conclusion involves accepting a null hypothesis so some consideration of possible Type II errors is required. The most plausible alternative hypothesis is that bl RTs are 80 msec greater than sm RTs; this would be expected if neither of the suppressed characters in bl displays contributed to making the classification. But even if only the first of the suppressed characters is assumed not to contribute and the weaker alternative hypothesis that bl RTs are 40 msec greater than sm RTs is considered, it may be rejected at the 0.001 level overall and at the 0.01 level for each of the 4 display conditions separately.

Classification Set	Display Condition	Bias	
		Speed	Accuracy
O/X	<u>sm</u>	349 (61)	418 (76)
	<u>bl</u>	367 (32)	427 (83)
digit/letter	<u>sm</u>	459 (66)	535 (110)
	<u>bl</u>	453 (77)	540 (107)

Table 1. Mean correct RTs (in msec) for the 8 conditions in Experiment II. (Each value in brackets is the standard deviation of the 8 means for individual Ss which are averaged to give the mean value shown.)

The analysis of error rates found no difference between the error rates for sm and bl displays and no difference between the error rates for sm and bl displays at the level of 20 and 25 Hz was not significantly different at

Classification Set	Display Condition	Bias	
		Speed	Accuracy
o/x	<u>sm</u>	18.2	2.9
	<u>bl</u>	12.1	2.4
digit/letter	<u>sm</u>	22.7	4.3
	<u>bl</u>	18.7	5.5

Table 2. Error percentages for the 8 conditions in Experiment II.

The analysis of error rates found no difference between the error rates for sm and bl lists and so the equality of sm and bl RTs was not merely achieved at the cost of a higher error rate in the bl lists.

Six of the 8 Ss mentioned spontaneously that the bl displays seemed to consist of only 3 characters. When specifically questioned about fixation all Ss reported that they had fixated in the centre of the displays as instructed. But all bl displays were grouped by themselves into bl lists and so in those lists the first character in each display always appeared in the fourth spatial position. Therefore it is possible that Ss intentionally or unintentionally fixated on this position, a little to the right of centre, and so perhaps gained some advantage with bl displays.

It is just possible perhaps that responses to bl displays were not initiated by the suppressed characters, but that bl and sm RTs were equal because sm responses were delayed by some effect specific to sm displays. This effect could have been some startle or overload effect produced by displaying 5 bright characters at once, although this seems implausible considering that Ss worked through lists of 200 such displays. The interpretation becomes even less likely when it is considered that any such delay to sm responses would

have to have been precisely equal to the presumed delay in bl responses produced by metacontrast. Further evidence that this interpretation is untenable comes from another experiment, which will not be described in detail because only 4 Ss were run before it became clear that overall RTs were changing so much with practice during a session that any effects of the independent variables were being overshadowed. The experiment was similar to Experiment II and, in particular, the different display conditions were presented in different lists. One analysis could reasonably be made on the data obtained and that showed that RTs for bl displays and to nb displays were the same, and that this was true for all 4 combinations of Speed and Accuracy, and of O/X and digit/letter conditions.

This experiment shows that a two-choice classificatory response may be triggered by suppressed characters, at least when different display conditions are grouped into separate lists, and even when accuracy is stressed and discrimination between digits and letters is required.

METHOD

Eight experimental lists of 170 displays and two practice lists of 50 displays each were prepared. Half the lists consisted of displays made up of O's and X's and the other half consisted of displays made up of digits.

Experiment III : Choice Responses with Display

Conditions Mixed.

In Experiment II the different display conditions were grouped into separate lists and so Ss may have adopted different viewing strategies with different lists. It was also possible that Ss obtained an advantage in bl lists by fixating selectively. The present experiment once again required Ss to classify displays into two classes, but the display conditions were mixed within lists and bl and blr, and nb and nbr conditions were mixed so that no single fixation position gave any special advantages.

One further condition was introduced: the first character to be presented was omitted from a randomly chosen half of the displays of each type so that any effect of the first character presented could be determined by direct comparison of performance on displays with and without the first character.

METHOD

Eight experimental lists of 170 displays and two practice lists of 50 displays were prepared. Half the lists consisted of displays made up of Os or Xs and the other lists consisted of displays made up of digits

(1,2,3,4,5,6,7,8 or 9) or letters (A,B,C,D,E,F,G,H, or I). Each display consisted of a single character repeated five times, except that the first character to be presented was replaced by a blank in half the displays of each type. Each list consisted of a random ordering of equal numbers of each of the eight possible display types: bl(4), bl(5), blr(4), blr(5), nb(4), nb(5), nbr(4) and nbr(5), where (4) indicates that the first character has been omitted from the display. The four display orders were such that positions 1, 2, 4 and 5 were each used as the first display position for one (4) order and one (5) order; these positions lie symmetrically about the centre and so there should have been no encouragement for S to fixate other than centrally.

Each character was presented for 20 msec and the SOA was 40 msec. The time between the onsets of successive displays, the S-S interval, was held constant at 1.5 sec, unless, as rarely happened, S had not responded within that time, in which case the next display was delayed and presented immediately after S's response to the preceding display.

Eight Ss each served in one Accuracy and one Speed session. In each session four lists were used, two for each of the classifications O/X and digit/letter. The order of sessions was counterbalanced over Ss and the

orders of use of lists and classification conditions were counterbalanced over sessions and Ss.

S was instructed to fixate in the centre of the screen and to press one of the two keys as quickly and accurately as possible to signal his classification of each display. The procedure used to induce a bias for speed or for accuracy was the same as that used in Experiment II.

RESULTS AND DISCUSSION

After the experiment had been run a serious error in the preparation of the list was discovered. The lists were exactly as intended except that the character omitted to give the (4) displays was the first (in time) to be presented only for the nb displays. The character consistently omitted from the other (4) displays was the 4th for bl, the 2nd for blr and the 5th for nbr. So the planned direct comparison between (4) and (5) displays would not say anything about the first character presented.

The first two responses in each list and the single response following an error were omitted from the analysis. In every case the RT was measured from the onset of the first character actually to appear on the screen i.e. from the earliest moment at which S had information on which to base a correct response. The mean correct RT and the percentage of errors were determined for every condition for every S and were subjected to two analyses of variance.

The first was a 5-way analysis of the arcsine transform of the percentages of errors and the factors were: Speed/Accuracy; O-X/digit-letter; bl/blr/nb/nbr; Ss; (4)/(5). The analysis showed that more errors were made in the Speed than in the Accuracy condition ($p < 0.005$) and more in the digit/letter than in the O/X condition ($p < 0.001$), and that the interaction between these two factors was significant ($p < 0.05$). No other main effect or interaction was significant and so once again consideration of RTs for the different display orders is not complicated by differing error rates or any consideration of speed-error trade-off.

The second analysis was similar to the first and was applied to the mean correct RTs. It showed that Speed RTs were lower than Accuracy RTs ($p < 0.01$) and the O/X classification was faster than the digit/letter classification ($p < 0.001$). No interaction was significant ($p > 0.05$) except that of Speed/Accuracy with (4)/(5) ($p < 0.05$). Table 3 shows the mean RTs relevant to this interaction and Table 4 the mean RTs for the different display orders.

The error in the list preparation did not directly affect the (5) displays since all these displays contained all five characters. Table 4 shows the mean (5) RTs for

Table 4. Mean correct RTs (secs) collapsed over Speed and Accuracy conditions and p s for Experiment III.

Number of letters
in each display

Speed

Accuracy

(4)

433

488

(5)

428

496

Table 3. Mean correct RTs (msec) for 4 conditions in Experiment III.

	Number of letters in each display		Mean of
	(4)	(5)	(4) and (5)
<u>bl</u>	464	469	466
<u>blr</u>	473	460	466
Mean of <u>bl</u> and <u>blr</u>	468	464	466
<u>nb</u>	452	463	458
<u>nbr</u>	455	462	458
Mean of <u>nb</u> and <u>nbr</u>	454	462	458

Table 4. Mean correct RTs (msec) collapsed over Speed and Accuracy conditions and Ss for Experiment III.

the different display orders and it is clear that the speed of classification is independent of display order. The mean for all (5) displays is 463 msec and this value may be compared with the overall mean RT of 443 msec for Experiment II. The two figures are both means over Speed and Accuracy, O/X and digit/letter, and different display order conditions. The standard deviations over Ss in Experiments II and III are 69 msec and 54 msec and so a difference of 65 msec is required for a significant difference (by t-test, d.f. = 14; 0.05 level) between the means of the two experiments. Therefore the observed difference of 20 msec does not approach significance, although this comparison across Ss is weak, and a common conclusion, that choice responses can be initiated by display onset, is warranted.

Turning to the (4) displays, the comparison most relevant to the aim of the experiment is that of bl and blr with nb and nbr RTs. The analysis of variance showed no relevant main effects or interactions to be significant, but a planned comparison of the 468 msec mean for bl and blr with the 454 msec mean for the nb and nbr conditions (see Table 4) shows a difference ($p < 0.05$). The effect of the preparation error, however, was to omit the first character from nb displays and the fifth from nbr displays so that the total duration of these displays was shortened. The characters omitted

from the bl and blr displays, on the other hand, were the 4th and 2nd respectively and so the total duration of these displays was the same as that of the (5) displays. Consequently any tendency for response to have been initiated very occasionally by the end of a display would have led to the nb and nbr, (4) RT being a little short, and this was precisely the case. This interpretation is also consistent with the interaction shown in Table 3, if it is assumed that any tendency for display offset to control response timing is stronger in the Accuracy condition, in which S is working more slowly and cautiously.

In summary this experiment indicates that letters suppressed by metacontrast can release a choice response, even when different display conditions are mixed within lists, and that they can do so even when accuracy is stressed and discrimination between digits and letters is required.

Experiment IV : Choice Responses with Warning-
Signal Controls.

It is possible that in Experiments II and III the choice response was indeed initiated by the first character presented, whether this was suppressed or not, but that this character only served as a warning signal and did not contribute to the perceptual processing leading to the choice of response. In other words perhaps the first character presented did initiate perceptual processes, but these processes were not ready to use information relevant to the choice of response until later when non-suppressed characters were available. If this argument were correct it would make no difference to replace the first character with, for example, a star, or any other character irrelevant to the classificatory response required. Experiment IV provides this control.

METHOD

This experiment was identical to Experiment III except that every display consisted of 5 characters. The 5 characters in a display were 4 occurrences of an O or X, or a digit or a letter, and one non-informative checker-board pattern formed by 12 dots in a rectangular grid the same size as other characters. For a randomly chosen half

of the displays the grid was the character presented first and for other displays it was the character presented second. These two types of display were called G1 ('grid first') and G2 displays respectively. A grid was presented in the control displays, in the second position, in case the grid was in some way distracting and so that there was no difference in overall appearance between the two types of display that may have led to an attentional bias.

Ss were instructed to ignore the grid and simply to make a classificatory response to the display as quickly and accurately as possible.

RESULTS AND DISCUSSION

As usual most Ss commented spontaneously that there appeared to be fewer than five characters in some displays. Five of the 8 Ss also commented that the grid in each display was hardly noticeable or was seldom seen at all. One S even asked why, after the change from the O/X to the digit/letter condition, the grid had been omitted entirely from the display. These observations are similar to those made by Mollon's (1969) Ss when trying to discriminate the orientation of a Landolt C presented twice with an intervening noise-field. In that situation the noise-field was seldom noticed. The effect is presumably

	O/X		digit/letter	
	G1	G2	G1	G2
<u>bl</u>	389	388	491	498
<u>blr</u>	377	401	492	498
<u>nb</u>	378	399	478	496
<u>nbr</u>	397	390	480	504

Table 5. Mean correct RTs (msec), averaged over Speed and Accuracy conditions and Ss, for Experiment IV.

	O/X		digit/letter	
	G1	G2	G1	G2
<u>bl</u>	7.7	2.4	10.7	4.4
<u>blr</u>	5.4	4.2	8.6	4.8
<u>nb</u>	5.9	2.7	8.0	6.8
<u>nbr</u>	10.7	1.8	9.4	5.6

Table 6. Error percentages, averaged over Speed and Accuracy conditions and Ss, for Experiment IV.

in each case the result of sustained attention to the relevant, informative parts of successive displays in a list.

The first two responses in every list and the response immediately following an error were omitted from the analysis. RTs were always measured from the first moment at which S had information allowing a correct response. So RT was measured from the onset of the second character in G1 displays and of the first character in G2 displays. RTs of less than 150 msec or more than 1500 msec were excluded and then RTs more than 3 standard deviations away from the mean of the remainder were also excluded. 0.8% of all responses were excluded in these ways.

The mean correct RT and percentage of error were calculated for each S for each condition. Two 5-way analyses of variance were conducted, one on the arcsine transform of the error percentages and the other on the mean correct RTs. The factors in each case were: Speed/Accuracy; O-X/digit-letter; Ss; bl/blr/nb/nbr; G1/G2.

The analysis of error rates showed that more errors were made in the Speed than in the Accuracy condition ($p < 0.001$) and more in the digit/letter than in the O/X condition ($p < 0.005$). More errors were made to G1 displays (8.3% errors) than to G2 displays (4.1%) ($p < 0.001$), this

factor interacted with bl/blr/nb/nbr ($p < 0.05$) and these two factors gave a significant 3-way interaction with O-X/digit-letter ($p < 0.05$). Relevant error percentages are shown in Table 6. No other main effects or interaction was significant ($p > 0.10$).

The analysis of mean RTs showed that Ss worked faster in the Speed than in the Accuracy condition ($p < 0.025$) and faster in the O/X than in the digit/letter condition ($p < 0.001$). The G1 RT (432 msec) was shorter than the G2 RT (444 msec) ($p < 0.005$), this factor interacted with bl/blr/nb/nbr ($p < 0.05$) and these two factors gave a significant 3-way interaction with O-X/digit-letter ($p < 0.001$). Relevant means are shown in Table 5. No other main effect or interaction was significant ($p > 0.10$).

It is clear that G1 displays were classified more quickly than G2 displays, but it remains to be discussed whether this only reflects a speed-error trade-off or some other effect irrelevant to metacontrast, or is specific to bl and blr displays. If it is specific to these displays it implies that the grid in G1 displays was helpful as a warning signal and so characters suppressed by metacontrast might not have been fully effective in controlling the choice of a response in Experiments II and III.

The G1 error rate was clearly more than the G2 error rate and so the 12 msec difference between the G1 and G2 mean RTs may be entirely explained by the operation of a speed-error trade-off. A reasonable mechanism for this follows simply from assuming a slight tendency to respond at a fixed time after display onset: since an informative character does not arrive until 40 msec after the onset of a G1 display a response given to such a display at the fixed time will follow a shorter period of perceptual processing relevant to the response choice

than would be the case for a G2 display. So it is more likely to be an error, but it will be recorded as a fast RT since RT is measured from the onset of the first informative character.

Interactions were observed of G1/G2 with display order. Tables 5 and 6 suggest that these do not indicate a different effect of the position of the grid for displays with and without metacontrast suppression, but rather that blr, G1 and nb, G1 displays are processed particularly quickly and accurately, especially in the O/X condition. These display orders are the two whose first characters are presented on the left of the fixation point, and so it is possible that left-to-right reading habits and perhaps cerebral dominance were responsible (see also Section 2.4).

It is possible that the grid has a general disruption effect and so the processing initiated by the first character in a G2 display may be interrupted by the arrival of the grid, or the grid may sometimes stop this processing with the result that processing must start again after the third character arrives. In either case G2 RTs would be lengthened and the effect would presumably be independent of display order.

Whatever causes the overall difference between G1 and G2 RTs, the important observation is that the size of the difference is no greater for bl and blr displays, for which it is 9 msec, than for nb and nbr displays, for which it is 15 msec.

This experiment shows, therefore, that the conclusions to Experiments II and III need not be qualified by admitting the possibility that the first, suppressed character might only be serving as a warning signal. The general conclusion must be that characters suppressed by metacontrast do indeed trigger normal choice responses.

5.4 Metacontrast suppression and physical dimming

Experiment V : Choice Responses and Physical Dimming

This experiment attempted to measure more accurately than had the previous experiments whether choice RTs to suppressed characters are of exactly normal length, and also to discover whether metacontrast suppression resembles physical dimming in its effect on choice RT (see Section 2.2). Once again ss made keypress responses to classify displays as consisting of letters or digits.

METHOD

Four Ss served for four sessions each in this experiment. All were very experienced in RT and perceptual experiments and one had served in Experiment VI more than a year earlier, but all were naive about the purposes of the experiment.

After a long series of pilot experiments it seemed best to make the main comparisons required within lists to reduce error variance, and to make the two main comparisons within separate lists so that in each type of list the two types of display would be equally frequent and so RT could not be distorted by the effect of different display frequencies.

Twenty-four experimental lists of 162 displays and two practice lists of 82 displays were prepared. All displays consisted of 5 occurrences of a single letter between A and I or a digit between 1 and 9; displays consisting of Os or Xs were not used in this experiment. Half of the lists were M ('metaccontrast') lists and half were D ('dimming') lists. M lists were a random mixture of equal numbers of bl and blr displays and of ct ('control') and ctr ('control, reversed') displays. ct displays consisted of 5 identical characters presented

successively in the order $\overset{2}{4} \overset{1}{5} 3$, which means that the 3rd and 4th characters were displayed in the same positions as the 1st and 2nd characters. ctr displays were presented in the order $\overset{1}{3} \overset{2}{5} 4$. These control orders were chosen because the first two characters were presented in exactly the same way as the first two in the bl and blr orders, the 5th character was at the fixation position as for these other orders, the total duration of all displays was the same and yet no masking or metacontrast suppression occurred in the control displays.

D lists were a random mixture of equal numbers of ct and ctr displays and of dm ('dim') and dmr ('dim, reversed') displays. dm and dmr displays were identical with ct and ctr displays except that the first character displayed was intensified on the screen only once, whereas all other characters were intensified 6 times during 6 consecutive display cycles to give the normal character presentation lasting 20 msec. SOA was always 40 msec and the S-S interval was 1.5 sec.

S was instructed to fixate in the centre of the screen, to ignore any differences of appearance among the displays and simply to make a keypress classification of each display as quickly as possible, but without making many errors. Separate Speed and Accuracy pay-off conditions were not used. A series of three M lists and a series of three D

lists were given in every session and every series was preceded by the appropriate practice list. The order of series was counterbalanced over sessions and Ss. Each S worked through each experimental list only once and the particular letter or digit in each display was chosen afresh, randomly, before a list was used for another S, to minimise any effect of particular display sequences in the lists.

The apparatus used did not allow fine or accurate control of display intensity but a coarse adjustment could be made. The usual display intensity was sufficiently high for a single intensification of, for example, two adjacent different letters to be seen very easily. So if RTs to dm and dmr displays were to be lengthened it seemed desirable to reduce display intensity while still ensuring that the single intensification of the first character in these displays was not too dim to be seen at all. Consequently, at the start of every session S was required to name the letters in successive displays consisting of a single intensification of two simultaneous, adjacent letters. Between displays the intensity control of the slave scope was adjusted with a screw-driver. An informal method of limits was used to set the display intensity at the lowest level which still allowed S to identify pairs of letters nearly perfectly. This setting was then used throughout the session.

Subject	M lists Difference in msec	D lists Difference in msec	Difference of the differences (msec)
SF	0.6 (7.6) $t(11) = 0.26$ $p > 0.25$	-12.7 (7.6) $t(11) = 5.75$ $p < 0.001$	13.2 $t(22) = 4.31$ $p < 0.001$
SV	2.3 (6.9) $t(11) = 1.07$ $p > 0.25$	-5.8 (12.1) $t(11) = 1.62$ $p = 0.13$	8.1 $t(22) = 1.94$ $p = 0.06$
TO	-5.2 (9.0) $t(11) = 2.01$ $p = 0.07$	-5.9 (8.0) $t(11) = 2.53$ $p = 0.03$	0.7 $t(22) = 0.19$ $p > 0.25$
MW	-0.6 (12.8) $t(11) = 0.16$ $p > 0.25$	-7.0 (14.2) $t(11) = 1.71$ $p = 0.11$	6.4 $t(22) = 1.16$ $p > 0.25$
Analysis over <u>Ss</u>	-0.74 $t(3) = 0.46$ $p > 0.25$	-7.82 $t(3) = 4.79$ $p = 0.02$	7.07 $t(3) = 2.74$ $p = 0.076$

Table 7. Mean differences in msec for each S for each type of list in Experiment V. The values in parentheses are standard deviations over lists. For M lists the difference is mean control RT, minus mean bl and blr RT and for D lists it is mean control RT, minus mean dm and dmr RT. Each difference is compared with zero and the t-values (d.f.11) and p values are shown. In the rightmost column the differences are compared for each S. In the bottom row the mean differences are compared with zero. All p values are for two-tailed tests.

RESULTS AND DISCUSSION

Ss reported that they very quickly learned to do the task 'automatically', with a stable error rate of 4 to 10%, and scarcely noticing differences of appearance among the displays.

The first two responses in every list and the response immediately following any error were omitted from the analysis. RTs less than 150 msec or greater than 1000 msec were excluded and then RTs more than 3 standard deviations from the mean of the remainder were also excluded. 1.2% of responses were discarded in these ways. The mean correct RT and the percentage of error were calculated for each type of display in each list.

M lists allowed a comparison of bl and blr displays with ct and ctr displays to be made. For each M list the mean RT for bl and blr displays was subtracted from that for the control displays. There were 12 such difference scores for each S. Similarly, for each D list the mean RT for dm and dmr displays was subtracted from that for control displays and once again 12 difference scores were obtained for each S. The mean and standard deviation of each type of difference score for each S are shown in Table 7. All mean differences were compared with zero and Table 7 shows that none of the M differences differed from zero at the 0.05

level while 2 of the D differences did differ from zero ($p < 0.05$). The other two D differences just failed to differ from zero at the 0.05, one-tail level. The bottom line of the table shows that the mean M difference did not differ from zero ($p > 0.25$), while the mean D difference did ($p = 0.02$, two-tailed). Two M differences went in each direction but all 4 D differences were in the expected direction.

The analysis so far shows that RTs to bl and blr displays were exactly the same length as those to control displays and that RTs to dm and dmr displays were longer than those of the control displays.

But was the difference between the differences real? The rightmost column of Table 7 shows that it was in the expected direction for all 4 Ss, was highly significant for one S and just significant for another ($p = 0.06$, two-tailed, so $p = 0.03$ one-tailed), but was not significant for the other two Ss ($p > 0.25$). The bottom right-hand cell of the table shows that the mean difference between the differences was just significantly different from zero on a one-tailed test ($p = 0.038$), even though only 3 degrees of freedom were available.

since the first conclusion implies that the subject's choice response is initiated at the onset of the display, when the first character is present by itself or full assembly, even if processing of this character is later suppressed and the character is not seen.

An analysis identical to that of mean RTs was carried out for the percentages of error. In M lists the bl, blr error rate (6.7%) was not different from the error rate for control displays (8.0%) either overall or for any individual S. In D lists the error rates for dm and dmr displays (7.6%) and for control displays (5.9%) did not quite differ overall ($p = 0.06$, two-tailed), although the difference was in the same direction for every S and reached significance for one S ($p < 0.01$). The difference between the differences was significant overall ($p < 0.025$) and for 2 Ss individually ($p < 0.05$).

The observed pattern of error rates fits conveniently with the RT results. In M lists, bl and blr displays gave performance that did not differ in speed or in accuracy from that for control displays. In D lists, on the other hand, the dm and dmr displays gave performance which was both slower and less accurate than that for control displays.

This experiment showed that choice responses to suppressed characters are of normal length and accuracy and, in particular, that metacontrast suppression is not similar to physical dimming in its effect on choice responses. This last conclusion is certainly reasonable since the first conclusion implies that the selection of a choice response is initiated at the onset of the display, when the first character is present by itself at full intensity, even if processing of this character is later suppressed and the character is not seen.

CHAPTER 6

Visual Search in Metacontrast

Experiment VI: Ss search for single-letter targets in metacontrast displays of random letters; many but not all suppressed targets are detected, and Ss fall into two classes.

~~For our present purposes, we will assume that the two classes of subjects are equally represented in the sample.~~

Experiment VII: the two classes resemble Speed and Accuracy performance; relatively more suppressed than other targets are missed in Accuracy conditions.

Experiment VIII: a go/no go response task forces Ss to use a stricter criterion and many suppressed targets are missed.

6.1 Visual search

Neisser (1963, 1964; Neisser, Novick and Lazar, 1963) presented Ss with long lists of random letters and required them to locate single target letters in the lists as quickly as possible. Rabbitt (1964) required Ss to sort cards into piles according to which of a small set of target letters was shown on the card, embedded in various number of irrelevant background letters. In each case Ss had to scan quickly through a display looking for a single target letter, or one of a small set of target letters. Sternberg

(1966, 1967) studied the converse task: Ss were given a single probe digit and had to scan through a short list of digits held in memory and decide whether or not the probe digit appeared in the list. Numerous papers based on the ideas and experimental paradigms of these early studies have now appeared; Rabbitt (1971) provided a review.

For our present purposes the visual search task is useful because it requires S to undertake perceptual analysis of an intermediate degree of complexity. If S must scan through a small number of random letters and decide whether a G, for example, is present, he must carry out more processing than is required merely to initiate a simple response, but visual search findings suggest that in many situations he need not fully identify every letter. This is the task used in the three experiments described in this chapter and our interest is in the efficiency, measured by RTs and error rates, with which Ss can detect targets which happen to be in positions suppressed by meta-contrast. Study of the visual search literature suggests that the complexity of the perceptual processing carried out by S could be manipulated by changing, among other variables, the display size, the number of possible targets, the number of possible background characters, the level of practice, or the bias for speed or accuracy. But in these experiments only the bias and the type of response required, either two-alternative forced-choice or go/no go, were manipulated; the task was always to scan through displays of five random letters looking for a single target letter.

6.2 Visual search in metacontrast

Experiment VI : Exploration of Visual Search in Metacontrast

This is an exploratory experiment in which Ss gave keypress responses to successive displays to signal whether or not they judged each display to include a single target letter. Both am and bl displays were used and several different SOA values were used for the bl displays.

METHOD

Six lists of 200 displays were prepared. Every display consisted either of 5 letters selected randomly with replacement from 25 letters of the alphabet, or of 4 such random letters and a single occurrence of the other letter, which served as a target. Each display contained a target with $p = 0.5$ and targets occurred with equal probability in the five display positions. The different lists contained different targets and the six targets used were B, D, F, N, P and X.

The letter presentation time was always 20 msec and the R-S interval was 1.0 sec. The display order was

always that for bl, but several values of SOA were used: 0, 20, 30, 40, 60 and 100 msec. Note that the bl order with an SOA of zero gives effectively an sm display. Any SOA value could be used with any of the lists, but the SOA value was held constant for all the displays in a list.

Twelve Ss each served for one session. Every S worked through all six experimental lists and was given each of the six SOA values. The orders of use of the lists and of SOA values were counterbalanced over Ss. The assignment of the 'target' and 'no target' responses to the two keys was changed from list to list within Ss. Ss were instructed to fixate a dim spot presented in the centre of the screen before each list began and to keep looking in that same position throughout the list. They were instructed to work quickly, but without making many errors.

Before each list S was told what the target would be for that list and which key to use to signal target and which to use to signal no target.

RESULTS AND DISCUSSION

The first response in each list and the response immediately following any error were excluded from the analysis. Exclusion of some responses following each

error was necessary because such responses in a serial RT task are known to be atypical (Rabbitt, 1966). Limitation of the exclusion to one response following each error appeared justified because the R-S interval was fairly long (1 sec; Rabbitt used 20 msec) and because a preliminary analysis of the data indicated that although the mean RT of correct responses which immediately followed an error was, for some Ss, different from the mean of all correct RTs, that for subsequent responses was not.

Responses were then classified as correct or error responses by target occurrence (target present or absent) and, for displays containing a target, by target position. The first analysis was made by collapsing data within Ss across SOA values. It appeared that Ss divided into those who made more misses for suppressed targets (targets in positions 2 and 4) and those who made more misses for other targets (targets in positions 1, 3 and 5). The SOA values of 20, 30 and 40 msec were observed to give the strongest impression of metacontrast and these values correspond closely with those given as optimal by Mayzner (see Section 3.2). Accordingly the error data were combined over these 3 SOA values; Figure 6 shows the resultant means for individual Ss. It shows that 8 Ss (called M Ss after the shape of their error curves) made more misses for targets in positions 2 and 4 than for targets in other positions, while the remaining 4 Ss (called W Ss) made fewer misses when targets were in positions 2 and 4 than when in other

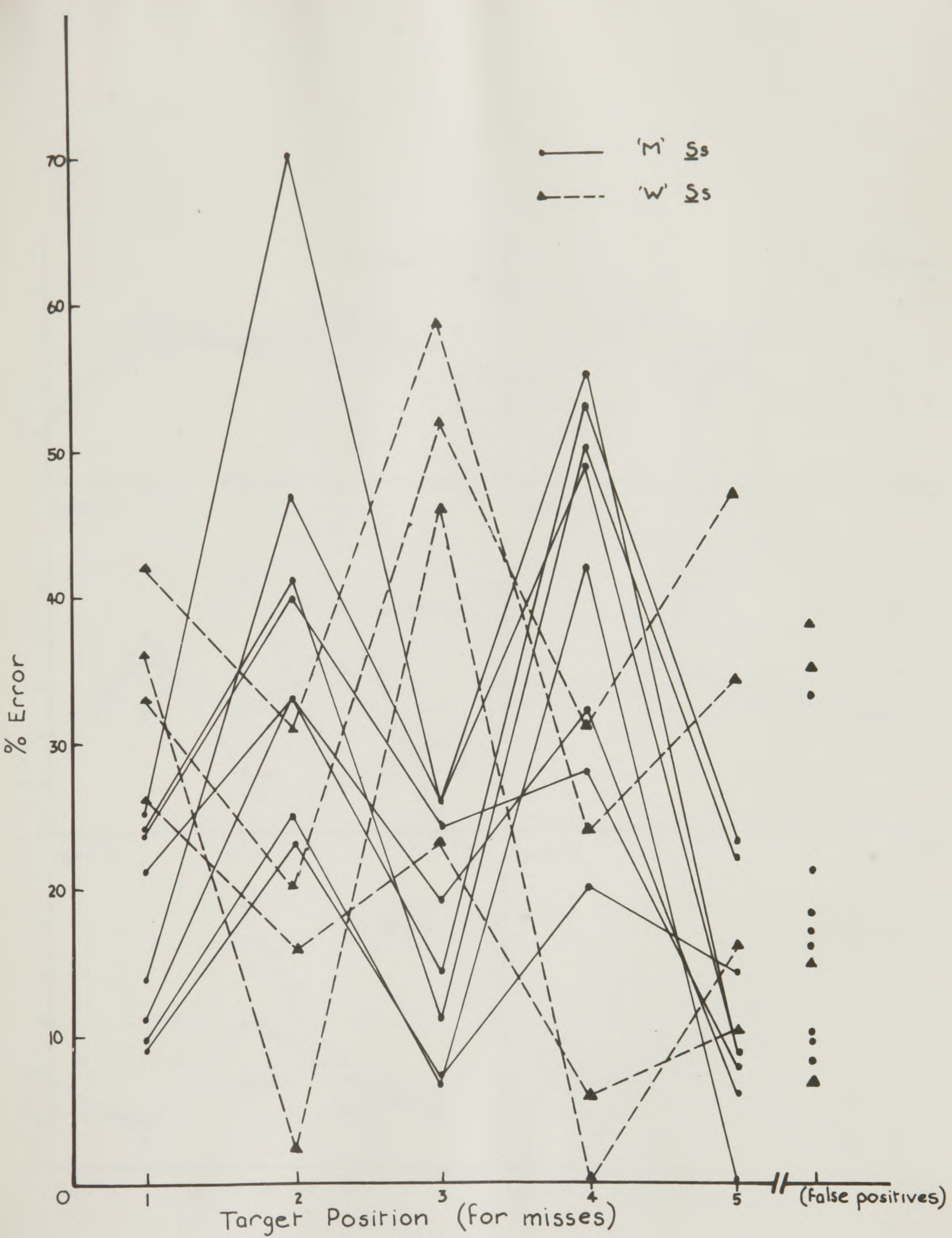


Figure 6. Experiment VI. Error data for individual Ss, for SOA 20, 30 and 40 msec.

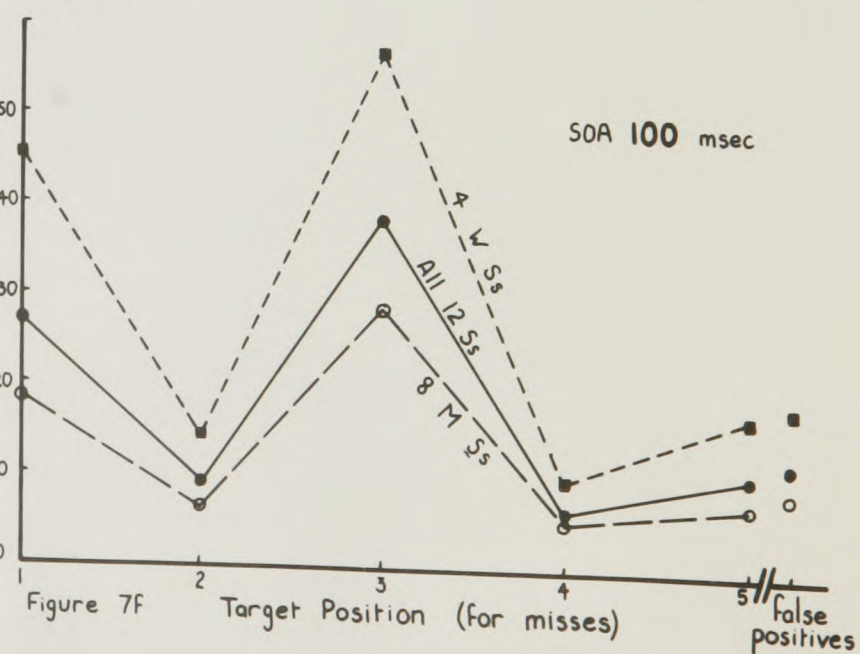
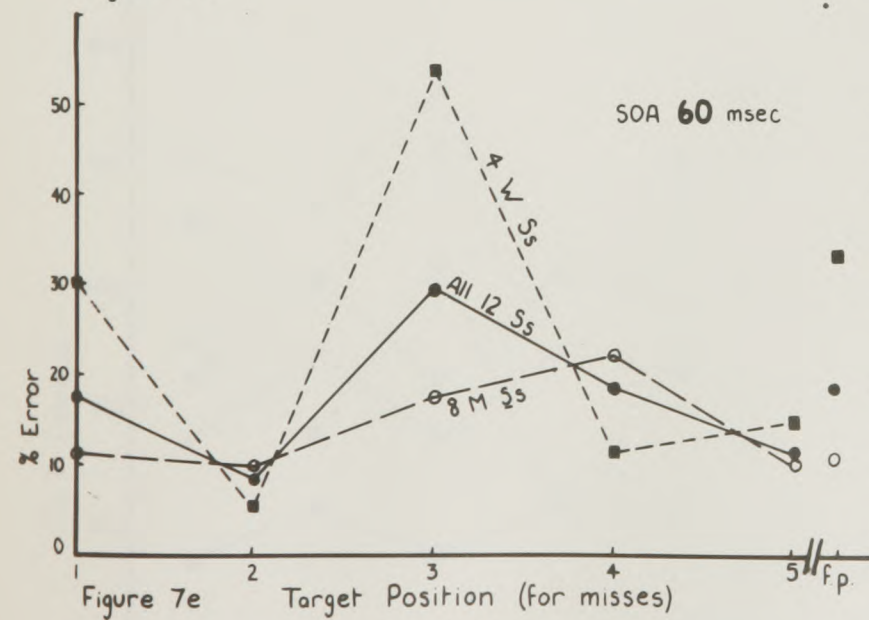
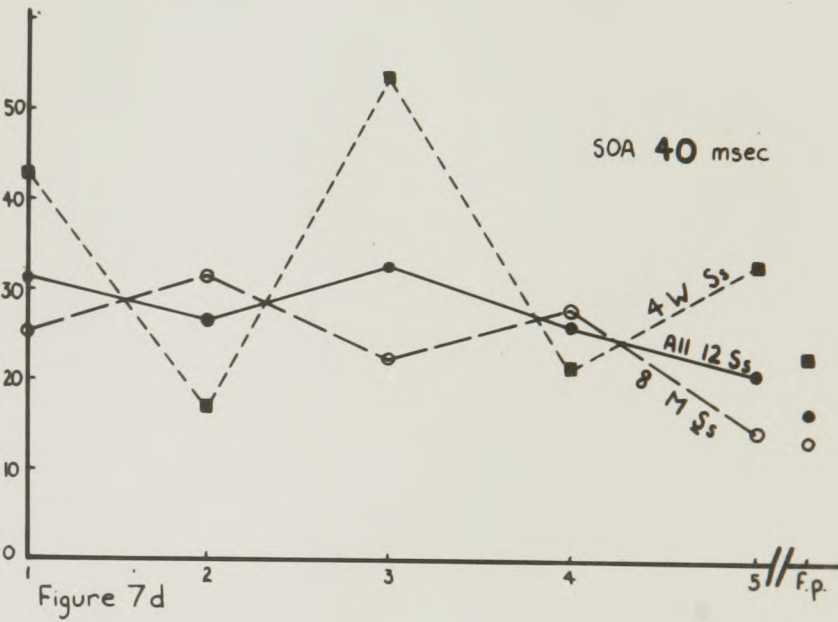
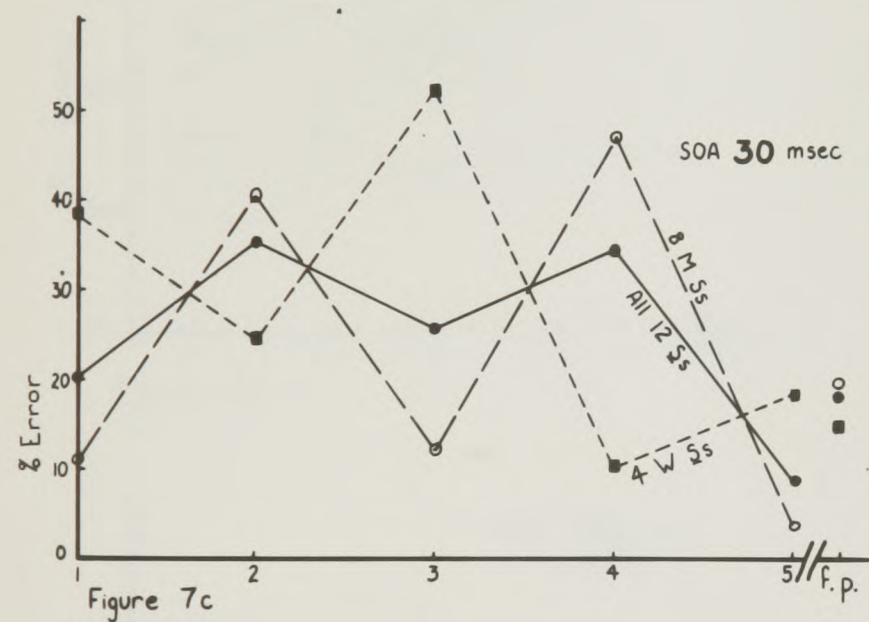
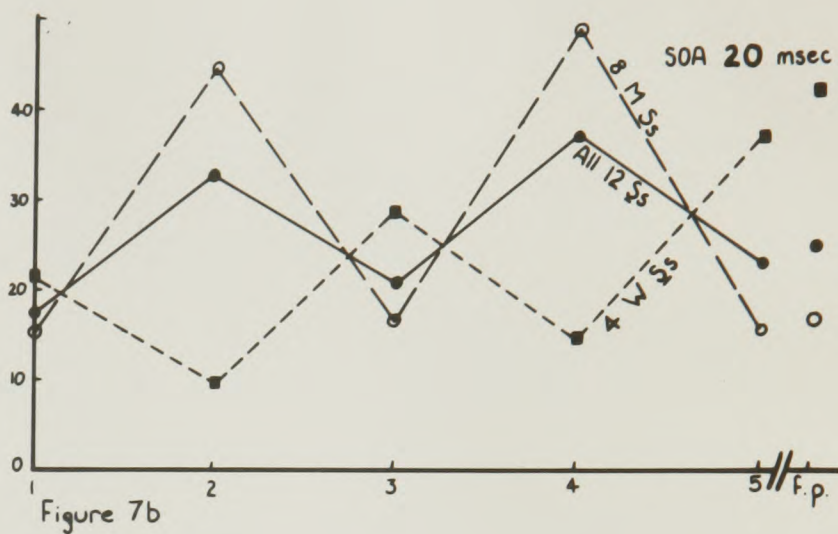
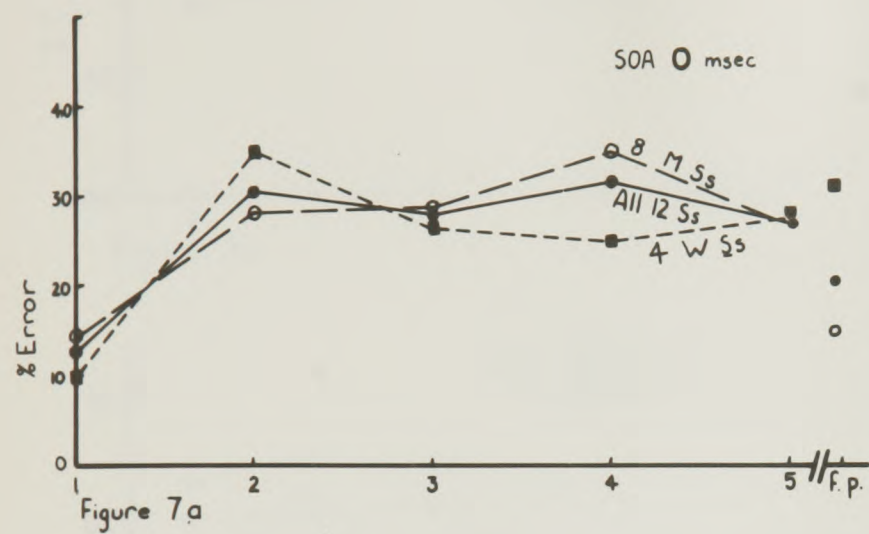


Figure 7. Experiment VI. Error rates at the six SOA values.

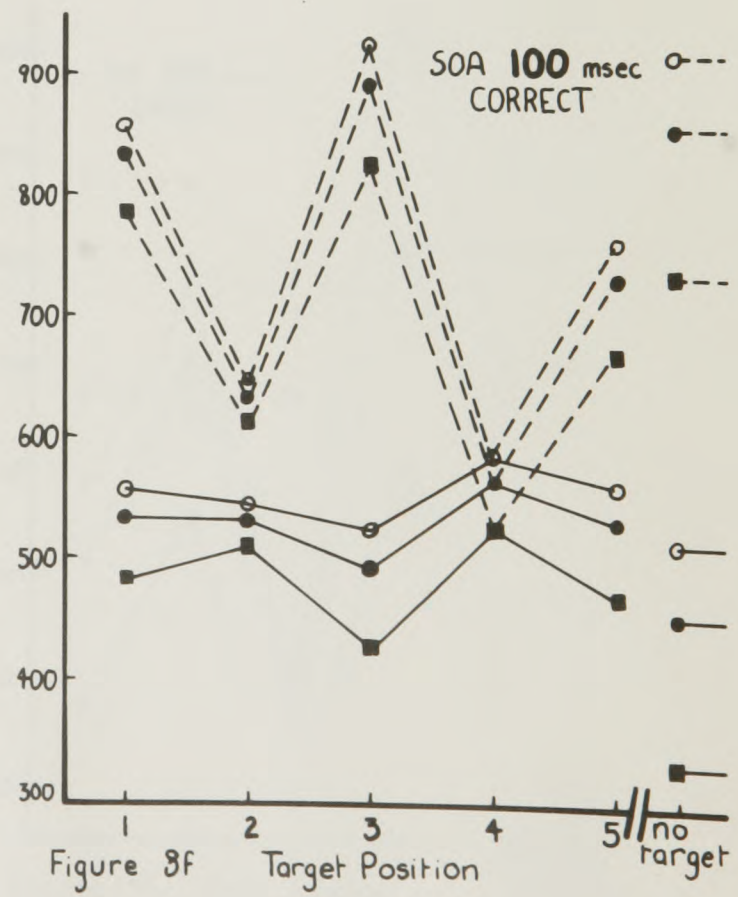
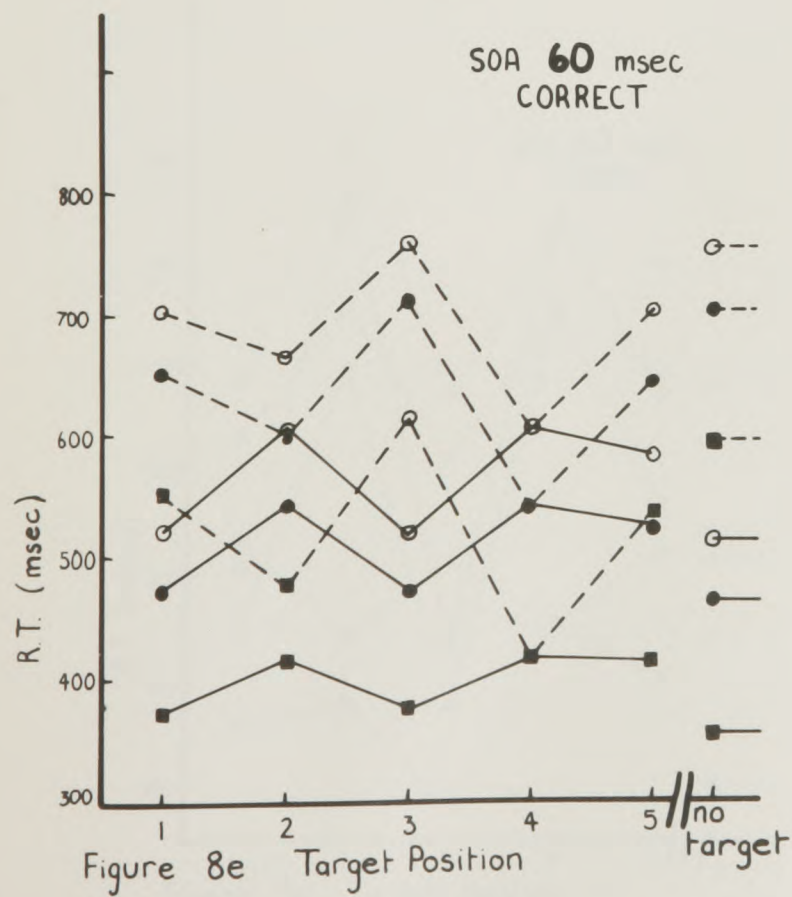
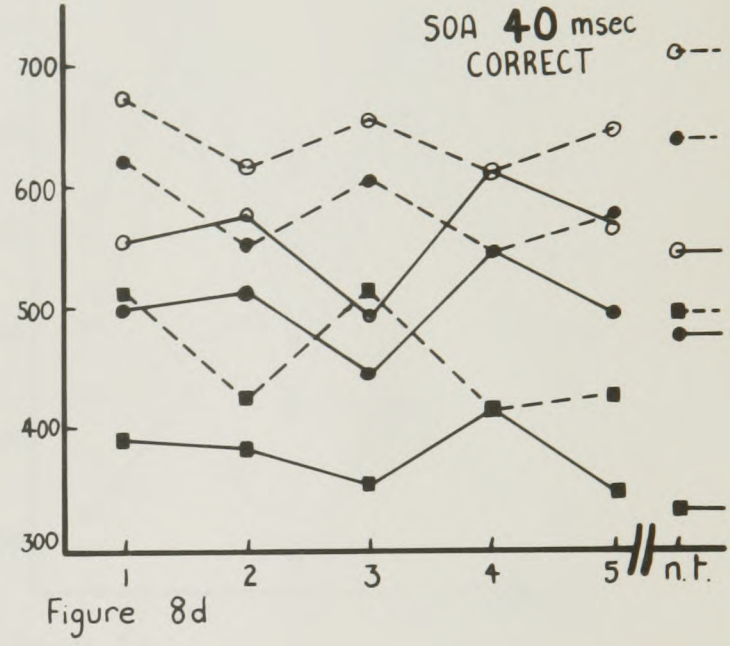
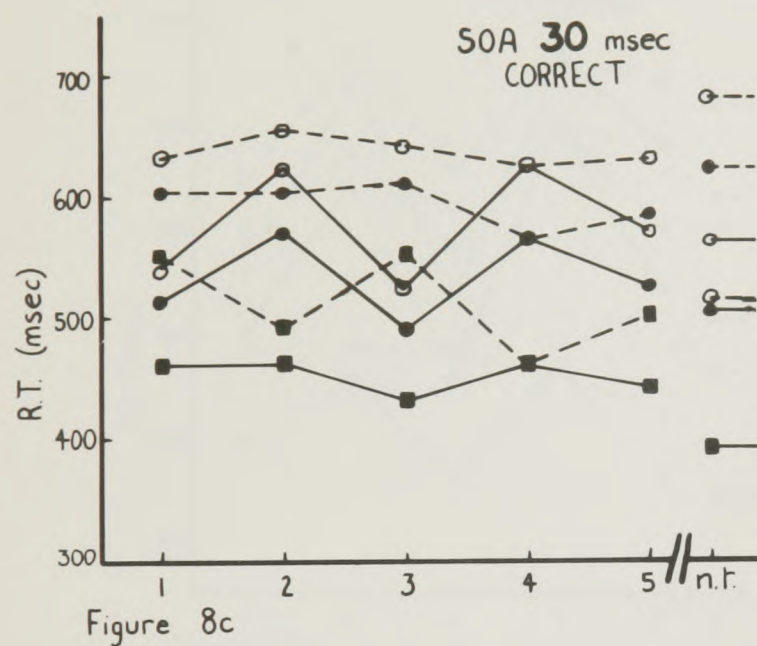
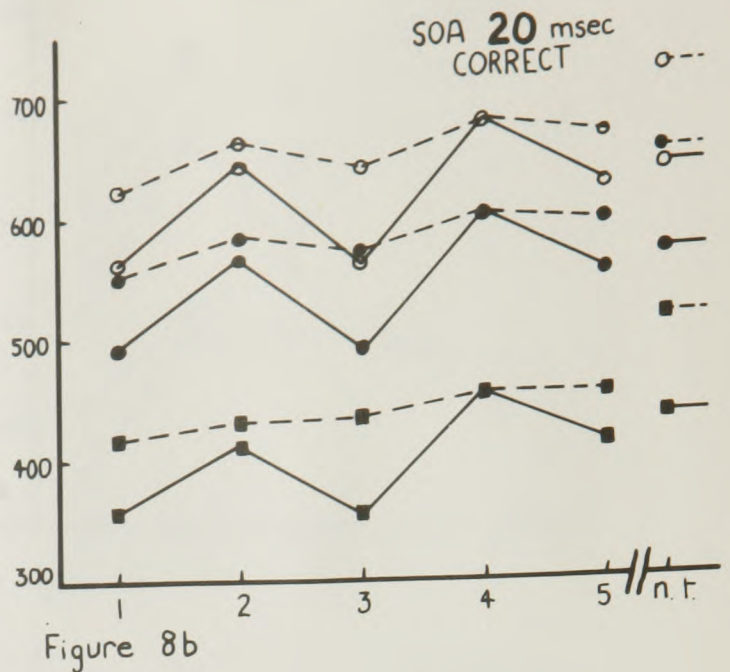
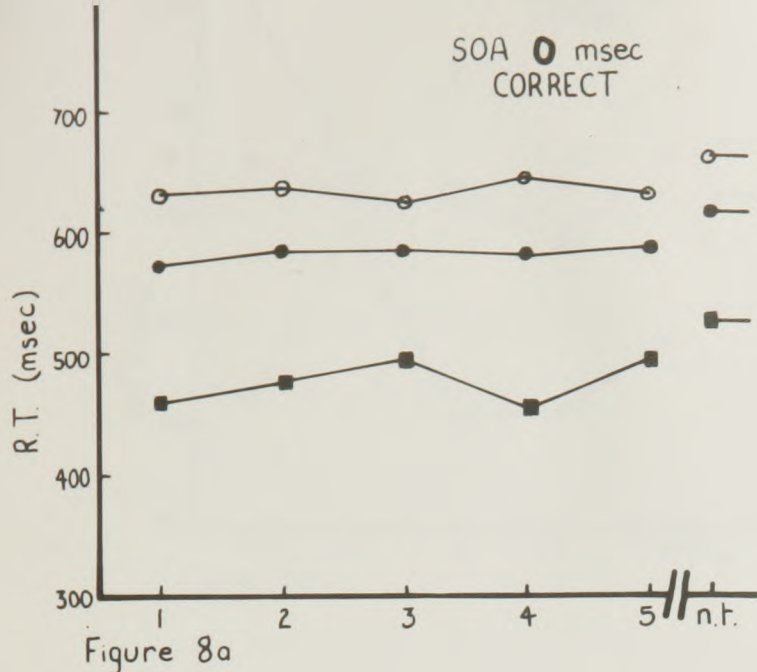


Figure 8. Experiment VI. Correct R.T.s at the six SOA values.

	All 12 Ss	8 M Ss	4 W Ss
Adjusted R.T.	—●—	—○—	—■—
Raw R.T.	- - -●- - -	- - -○- - -	- - -■- - -

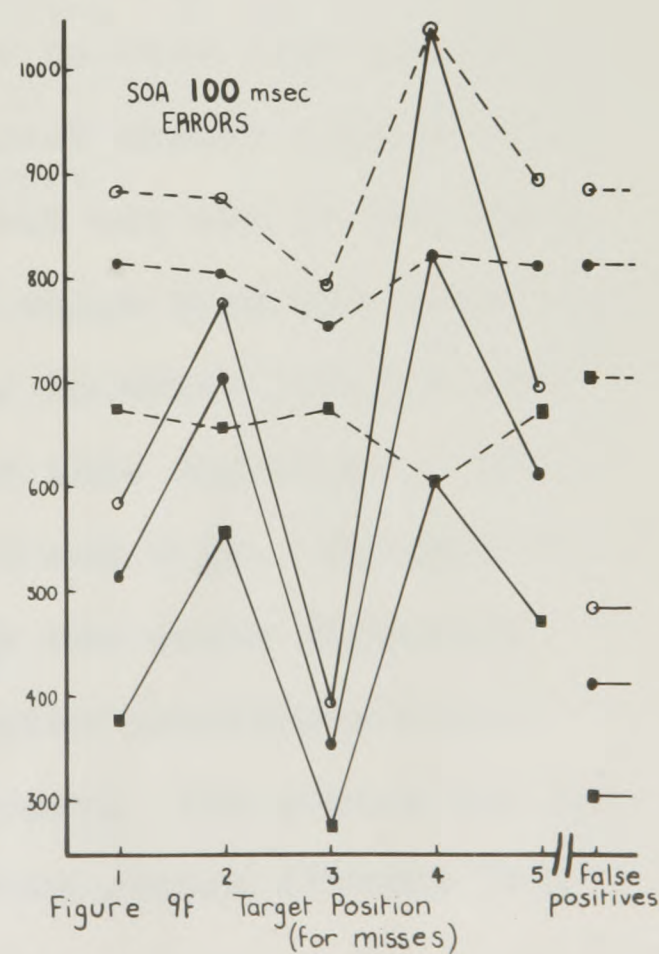
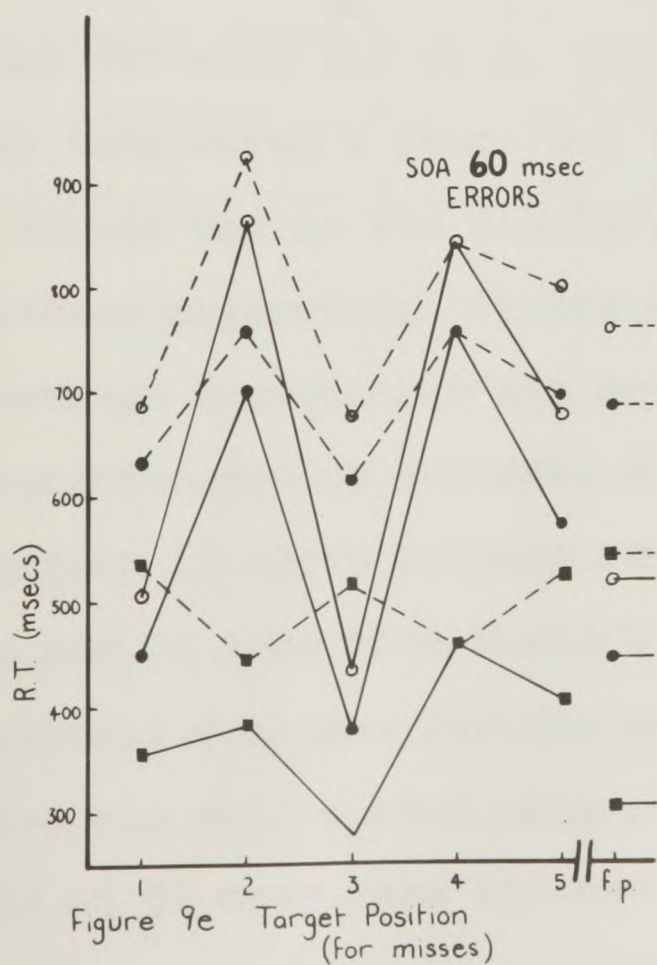
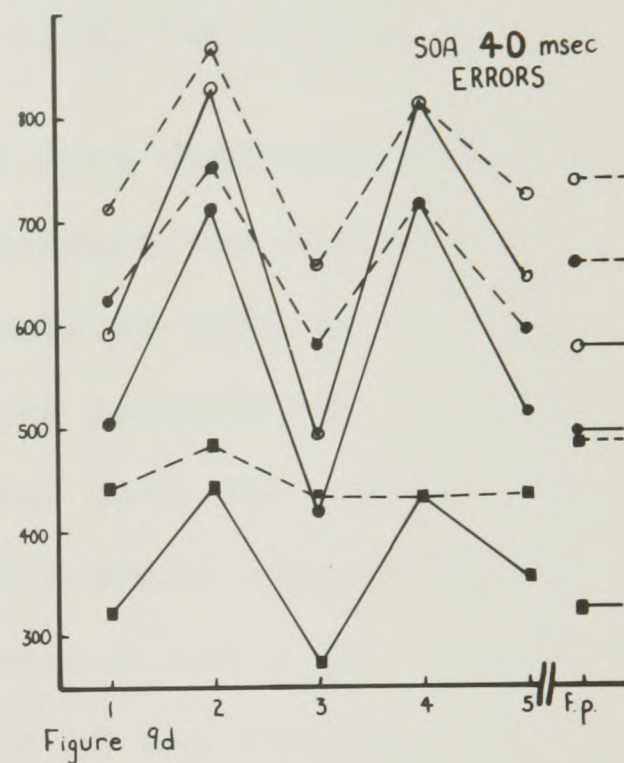
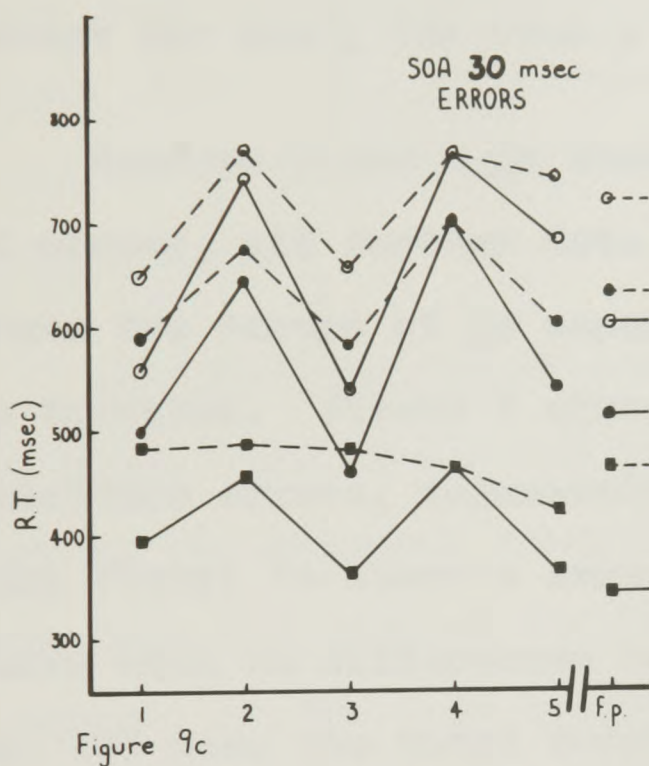
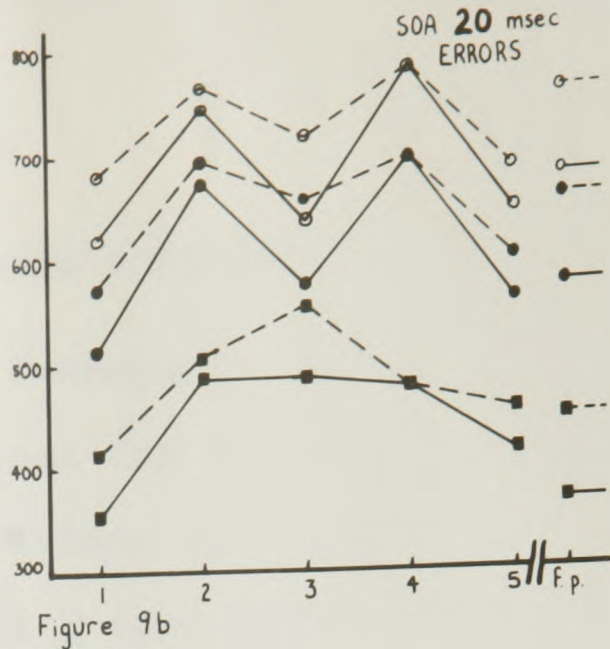
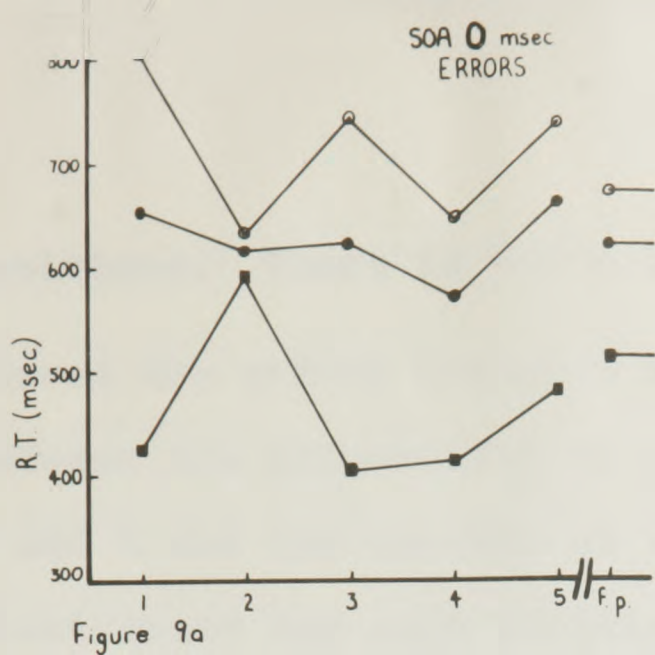


Figure 9. Experiment VI. Error R.T.s at the six SOA values.

	All 12 Ss	8 M Ss	4 W Ss
Adjusted R.T.	—●—	—○—	—■—
Raw R.T.	- - -●- - -	- - -○- - -	- - -■- - -

positions. There is not a single reversal: the 12 curves are either M-shaped or W-shaped. The difference between the proportions of misses for targets at positions 2 and 4 and for targets at positions 1, 3 and 5 was significant for each individual S ($p < 0.05$ or better), except for one S for whom $p < 0.10$, two-tailed.

Because M and W Ss showed such different patterns of errors, all further data analysis was carried out for these two groups of Ss separately as well as for all 12 Ss together. Figure 7 gives the percentages of responses which were errors, separately for each SOA value. For SOA zero Figure 7a shows a straightforward display position curve with no differences between M and W Ss. When SOA was 100 msec the total duration of the display was more than 400 msec and so Ss, trying to give fast responses, may have given a premature target absent response when a target was in the display, but was one of the later letters presented. Figure 7f shows that the error percentages increase in the order in which letters were presented and so suggests that this did occur. This pattern is shown by both the M and W Ss. Figures 7b, 7c and 7d show that M and W Ss had quite different patterns of misses for the display conditions which show the most marked metacontrast. The curves for an SOA of 60 msec take intermediate shapes (Figure 7e).

One notable feature of the error rates is that they were so low, indicating that many suppressed targets were detected. Averaging over all Ss, 69.5% of targets in positions 2 and 4, with SOA values of 20, 30 or 40 msec, were detected. This proportion is similar to that obtained under some conditions by Andreassi, Mayzner, Beyda and Waxman (1970) when they required Ss to identify the letter presented in positions 2 and 4 of a blank display (see Section 3.4).

For the purposes of analysis, RTs were expressed in two ways. Raw RT was the time from the onset of the display to the keypress response, while adjusted RT was the time from the onset of the target, for displays containing a target, or the last letter presented, for displays without a target, to the response. So the adjusted RT was measured from the moment at which S first had sufficient information for a correct response.

Figures 8 and 9 show correct and error RTs separately for each SOA value. The most striking result is that in every single condition plotted the M Ss had longer RTs than the ^WSs and so this difference is clearly significant and pervasive. For small SOA values (0, 20 and 30 msec) the raw correct RT curves are fairly flat as if S waited until the end of the display before deciding and responding. For SOA = 100 msec, however, the adjusted correct RT curve is close to flat as if letters arriving at 100 msec intervals

initiated response independently. Curves for intermediate SOA values show a confused pattern of intermediate shapes. Perhaps the only other clear result is that for SOA values of 20, 30, 40 and 60 msec the errors made by M Ss to targets in positions 2 and 4 were much slower than errors to other targets ($p < 0.001$ at each SOA value, whether raw or adjusted RTs are considered). In other words, M Ss not only missed a large proportion of suppressed targets, but their responses in doing so were slow. W Ss showed no clear tendency to make slower errors for targets at any particular positions.

Two further points relevant to the differences between M and W Ss arise from the data. It was mentioned above that the mean raw RT for correct responses immediately following an error was, for some Ss, different from the overall mean correct RT. This difference was not significant for 7 Ss, but did reach significance ($p < 0.01$) for the other 5 Ss. Three of these Ss were in the W group and for each of them responses following errors were unusually fast. The other 2 Ss for whom the difference reached significance were in the M group and their difference went in the other direction: responses following errors were unusually slow. An elementary probability calculation shows that such a strong correspondence of direction of

difference to group is significantly extreme ($p = 0.014$). This difference between the groups could, however, have been produced by other differences such as different mean RTs and different proportions of errors of various types.

The final difference observed between the performance of the M Ss and that of the W Ss comes from a comparison of correct and error RTs. Combining data for all SOA values for the 8 M Ss, the average correct RT was 575 msec and the average error RT was 650 msec. So errors were slow and the difference was 75 msec and significant ($p < 0.001$). Also, the difference was in the same direction for each of the 8 Ss individually. For the 4 W Ss, the average correct RT was 425 msec and the average error RT 357 msec. So errors for these Ss were fast and the difference was 63 msec and significant ($p < 0.001$). Three Ss showed differences in this direction and for the fourth, error RT was just 2 msec longer than correct RT.

In summary, two quite distinct patterns of behaviour have emerged. The 8 M Ss gave slow responses and their errors were even slower. Their average error percentages were 21.5 for misses and 14.1 for false positives. Error patterns showed that suppressed targets were missed often and RTs showed that responses to suppressed targets were slow, particularly if the target was missed. The 4 W Ss,

on the other hand, gave correct responses which averaged 150 msec faster than the M Ss' correct responses. Their errors were even faster. However, their miss and false positive error percentages were both significantly greater ($p < 0.001$ in each case) than those for the M Ss. 26.9% of targets were missed, and 27.1% of displays without a target gave rise to a false positive response. Error patterns showed that suppressed targets were missed relatively infrequently and RTs showed that when such a target was detected the response was faster, or at least no slower than other detection responses.

It is certainly strange that Ss should divide so clearly into groups giving such very different patterns of performance. Perhaps the most plausible interpretation is to assume that the M Ss adopted a set for accuracy and deliberately worked slowly, whereas the W Ss emphasised speed. The faster overall performance and greater proportions of misses and false positives shown by the 4 W Ss are certainly consistent with this interpretation. It is not so straightforward, however, to interpret the different directions of the difference between correct and error RTs observed in the two groups, because errors may occur for a variety of reasons. But it may be plausible to say that errors were faster than correct responses for the W Ss (those presumed to adopt a bias for speed) because

errors occurred when S tried to respond too quickly, and that impulsive motor errors were likely to occur and to be fast.

Henmon (1911) observed that 'there are indications of two types of wrong judgements with reference to time, those that are rendered too quickly and those that are prolonged beyond the optimal time'. Rabbitt (1966, 1969) also discussed error RTs and presented evidence that errors are usually faster than correct responses in serial choice response tasks. Kellogg (1931), Rabbitt and Vyas (1970) and Wilding (1970, 1971) studied situations in which errors are slower than correct responses. Such tasks are typically those in which discrimination is difficult, and then when errors are made they are not only slow, but they are assigned low confidence ratings by Ss. Search for targets in metacontrast may indeed require Ss to make difficult discriminations, and this aspect may have been more important for M Ss, who are assumed to have adopted a bias for accuracy. This interpretation is certainly plausible for the slow responses made by M Ss when they missed a suppressed target, for discrimination may have been most difficult in just this case. The prediction would then be that confidence ratings would be low when an M S does miss a suppressed target.

If the interpretation in terms of accuracy and speed biases explains the differences between M and W Ss fully, then the experiment shows nothing about metacontrast beyond the simple observations that, first, many suppressed targets were detected and, second, far from all such targets were detected. The only other remarkable finding would be that Ss divided so sharply into two groups, rather than showing patterns of behaviour distributed along some line joining a strong speed bias pattern and a strong accuracy bias pattern, as would be expected considering the neutral nature of the instructions ('work quickly without making many errors'). This finding suggests that the easiest strategies to adopt in this particular task involve adoption of strong speed or accuracy biases, and these may correspond to selective attention to the early, suppressed positions, or to the later positions respectively.

There are, however, findings suggesting that there is still more to be explained. If W Ss detected more suppressed than easily visible targets simply because they gave many premature target absent responses, then their RTs to missed unsuppressed targets should have been fast, and this was the case for SOA = 30 msec or more. But for SOA = 20 msec, Figure 9b suggests that there was no tendency for misses of unsuppressed targets to

be especially fast, although Figure 7b shows a pronounced W shape for the error curve when SOA = 20 msec. Also, Figure 8b shows that for W Ss the raw RT curve for correct responses when SOA = 20 msec is close to flat, suggesting that S waited until the end of the display before initiating a response, so the observed pattern of misses can hardly be attributed solely to premature target absent responses. Neither of these observations is easily handled by an explanation in terms of a simple bias for speed, but both are consistent with the idea that suppressed targets may be detected efficiently if a particularly fast decision and response are made.

Another observation not easily accounted for by a bias interpretation is that ^W/_{1/2} Ss missed far fewer suppressed targets than did M Ss and this was the case for SOA values of 20, 30 and 40 msec. This observation again leads to interesting speculation along the lines of that first given in Section 3.5: suppressed targets may have been detected more readily when S was set to make a very early decision than when S was proceeding slowly and cautiously. In other words, suppressed targets may have been available for analysis when presented, but were removed, in some sense, very soon after first appearing. The slow responses made by M Ss when missing blanked targets would then be described as occurring because the arrival of a target in

position 2 or position 4 was registered in the nervous system, but by the time S came to choose his response knowing in which position a target had been presented no sensory evidence that a target had been presented remained, so S, puzzled, made a slow, incorrect, target absent response.

The different detection rates for suppressed targets shown by M and W Ss may, however, have been produced by different response biases. If, for example, W Ss not only worked quickly but preferred making target present responses, then a high detection rate for suppressed targets might have been achieved but at the expense of a high false positive rate. In the terminology of signal detectability theory, our speculative hypothesis holds that discriminability (d') for suppressed targets was greater for W than for M Ss, while the response bias interpretation holds that the difference was merely due to a difference in setting of criterion (β). Figures 7b, 7c and 7d show that W Ss did detect more suppressed targets than M Ss, but also that they made more false positive responses (except for a small reversal at SOA = 30 msec), so the response bias interpretation cannot be disregarded.

It seems plausible that discriminability and criterion effects may both be important in this visual search task and that their effects may be distinguishable. But there

is one difficulty in applying the theory of signal detectability here and this is simply that there is no way of knowing in which position S wrongly detected a target when he made a false positive response.

The observed hit rates (HR: the proportion of targets detected) and the false alarm rates (FAR: the proportion of displays without a target to which S gave a target response) were used to determine estimates of d' and β . The hit rates were for targets presented in positions 2 and 4 only. Two different assumptions were used in choosing the false alarm rates to use. Assumption (i) was that no errors of commission ever occurred to positions 1, 3 or 5 and that all false positives occurred because targets were mistakenly detected at positions 2 or 4, so that the FAR used was simply the overall value. Assumption (ii) was that false positives occurred equally frequently at each of the 5 positions and so only 40% of them were in positions 2 or 4. The FAR used was therefore 0.4 times the overall value. Having selected the appropriate HR and FAR values tables (Freeman, 1964; Swets, 1964) were consulted to determine the corresponding d' and β estimates. Estimates were determined separately for every S at each of the SOA values 20, 30 and 40 msec, for Ss combined into the two groups, and for the 3 SOA values combined.

SOA msec	Assumption	4 W <u>Ss</u>			8 M <u>Ss</u>		
		HR FAR	d'	β	HR FAR	d'	β
20	i	0.88	1.4	0.5	0.54	1.1	1.6
		0.41			0.16		
	ii	0.88	2.2	0.8	0.54	1.7	3.3
		0.16			0.06	2.9	
30	i	0.82	2.0	1.1	0.56	1.0	1.4
		0.15			0.20		
	ii	0.82	2.5	2.2	0.56	1.6	2.7
		0.06			0.08		
40	i	0.81	1.65	0.9	0.71	1.68	1.6
		0.22			0.13		
	ii	0.81	2.22	1.7	0.71	2.20	3.3
		0.09			0.05		
Average of all these	i	0.84	1.6	0.75	0.60	1.25	1.6
		0.26			0.16		
	ii	0.84	2.3	1.4	0.60	1.8	3.2
		0.10			0.06		

Table 8: Estimated values for discriminability (d') and criterion (β) for Experiment VI for the detection of targets in positions 2 and 4, by the two groups of Ss, under assumptions (i) that false positives only occurred in positions 2 and 4, and (ii) that false positives occurred equally frequently in each of the 5 positions.

Table 8 shows the results for the two groups of Ss. It appears that the absolute values of d' and β are sensitive to the FAR assumption made, but that the differences between values for the W Ss and the M Ss seem little affected. So it is not important which assumption is the more correct, but we do rely on the probably quite reasonable assumption that, whatever the distribution of false detections over positions, it is similar for the two groups of Ss.

Table 8 shows that for SOA = 40 msec the two groups had the same d' and so any performance difference must be explained by the stricter criterion of the M Ss. ($\beta = 1$ when there is no bias and $\beta > 1$ when the criterion is strict i.e. the bias is for target absent responses. $\beta < 1$ when the bias is for target present responses.) For the shorter SOA values, and overall, the W Ss had higher d' values as well as lower, less strict criterion values. But the analysis of values for individual Ss showed that, because individual variation was large, the only differences between groups to reach significance were the d' difference for SOA = 30 msec (2.0 was greater than 1.0; $p < 0.05$, two-tailed, by Mann-Whitney test) and the β difference for SOA = 20 msec (0.5 was less than 1.6; $p < 0.005$, two-tailed, by Mann-Whitney test). Averaging over the 3 SOA values only the β difference was significant ($p < 0.005$). So the different performance of the two groups in detecting suppressed targets may be ascribed largely to different response biases, but there is also some evidence that

the W Ss, those who worked quickly, had a larger d' than did the other Ss, when SOA was 30 msec. It is quite plausible that rapid response and a lax criterion should be associated, since the smaller amount of evidence required to satisfy a lax criterion can presumably be collected rapidly, or, conversely, if response is to be rapid only a limited amount of evidence can be collected. The results cannot assign primacy to either of these possibilities.

A second approach was taken to the possible relationship of speed ^{of response and a lax criterion} with accuracy in the detection of suppressed targets. Rank correlations over the 12 Ss were calculated between the mean RT for the detection of targets in positions 2 and 4 and the estimates made previously of d' and β for individuals. Correlations were determined for SOA values of 20, 30 and 40 msec separately and for the three values combined. Two correlations were significant and these corresponded with two of the three significant differences discussed in the preceding paragraph. For SOA = 30 msec, target detection RT was strongly and negatively correlated with d' ($\rho = -0.80$; $p < 0.005$) and the overall analysis showed that target detection RT was correlated positively with β ($\rho = 0.69$; $p < 0.025$). So once again we find that fast RTs for the detection of suppressed targets were associated with the accurate discrimination of such targets for the 30 msec SOA value. There was also a general tendency for these fast detection responses to be related to a lax criterion i.e. a bias towards giving target present responses.

The correlation of speed with accuracy over Ss does not guarantee that the same relation holds within Ss, for some Ss may have been generally good and given both fast and accurate performance while others were generally

bad and gave neither. The correlation over the same ss, however, of mean target detection RT with d' , for the zero SOA condition, was -0.02 . This value clearly does not differ from zero and so there is no evidence in this case for any important contribution from a general ability factor. Note also that the direction of the observed relation between RT and discriminability is in precisely the opposite direction from that expected on simple considerations of speed-error trade-off.

The general point may be made that the complexity of perceptual analysis required in the visual search task used in this experiment is not obviously much greater than that required for the letter-digit discrimination in the choice RT experiments described in Chapter 5. But many suppressed targets were missed in the visual search task, while metacontrast did not increase the choice RTs in the classification experiment. The important difference must presumably be that in the classification task only one character, the first to appear, need be classified whereas in the visual search task ss may have to classify every letter in the display as a target or a non-target.

Pilot work had shown that systematic quizzing of Ss about the appearance of the displays only led to confusion, and Ss reported that they 'looked for targets' most of the time and 'looked at the displays' some of the time, just so that they could answer questions about the displays' appearance. So no formal accounts of the subjective appearance of displays were required from Ss. Several Ss did, however, give spontaneous comments along the lines that in some lists they only saw three letters in each display and that many responses seemed to be made quite at random and, in particular, that they would sometimes find themselves making a fast 'target' response, with no recollection of having seen a target.

In summary this experiment provides evidence that observers can detect many but not all targets masked by metacontrast. Ss divided remarkably clearly into two groups, one of which (the W group) showed a pattern of performance suggesting a bias for speed while Ss in the other group (the M group) appeared to have adopted a bias for accuracy. Membership of the speed group and fast mean target detection RTs were both associated in general with a bias towards giving target present responses. There is also evidence that in some conditions the fast detection of suppressed targets was associated with accurate detection of them, even though

greater speed is usually associated with greater error and a loss of discriminability in such serial RT tasks. So suppressed targets appear to have been discriminated from background letters particularly efficiently when Ss adopted a bias towards finding targets and when they committed themselves to a target detection response very early. Once again it is possible that information was available at first and was then removed, and that this later removal is the phenomenon called metacontrast.

6.3 Speed and Accuracy Pay-offs

Experiment VII : Visual Search with Speed and Accuracy Pay-offs

The visual search task used in this experiment was similar to that used in the preceding experiment, but Ss worked under pay-offs either for speed or for accuracy. The aim of the experiment was to study the variations in performance which appeared, in the preceding experiment, to be related to Ss' biases for speed or accuracy, but with the same Ss serving in the two bias conditions.

METHOD

Eight experimental lists of 201 trials and one practice list of 50 trials were prepared. Every display consisted either of 5 random letters chosen without replacement from the 25 letters A-Y, or of 4 such random letters and the target Z. In every list a randomly chosen half of the displays contained a target and the others did not, and the target was equally often in each of the five positions.

Twelve Ss each served for two sessions, one in the Speed and one in the Accuracy condition. The procedure used for inducing the biases was the same as that used in Experiment II. Each S had his own single target letter and searched for just this target in all lists of both sessions. When B, for example, was required as the target, one of the TSCOPE programs replaced every B in the background of one of the standard lists with a Z and every target Z with a B. So each S searched through lists which were basically similar, but he was looking for his own target. The 12 targets used were B, G, H, J, L, N, P, S, R, X, Y and Z.

The letter presentation time was 20 msec and the S-S interval was held constant at 1.5 sec. This change to a constant S-S interval from the constant R-S interval used in Experiment VI was made so that overall rates of working would be the same in the Speed and Accuracy conditions, even though the mean RTs might well differ.

Three types of presentation were used: sm, bl and nb and the SOA was 40 msec for the bl and nb conditions. The type of presentation was always constant within a list. One sm, one nb and two bl lists were presented in each session. The order of sessions was counterbalanced over Ss and the orders of presentation of the different display conditions and of use of the eight lists were counterbalanced over sessions and Ss.

To avoid confusion, the assignment of responses to the two keys was counterbalanced over Ss but kept constant for each single S.

Figure 10b. Experiment VII. Error rates for 12 Ss (2 sessions).

	Speed	Accuracy
<u>sm</u>	○	○
<u>nb</u>	●	●
<u>bl</u>	■	■

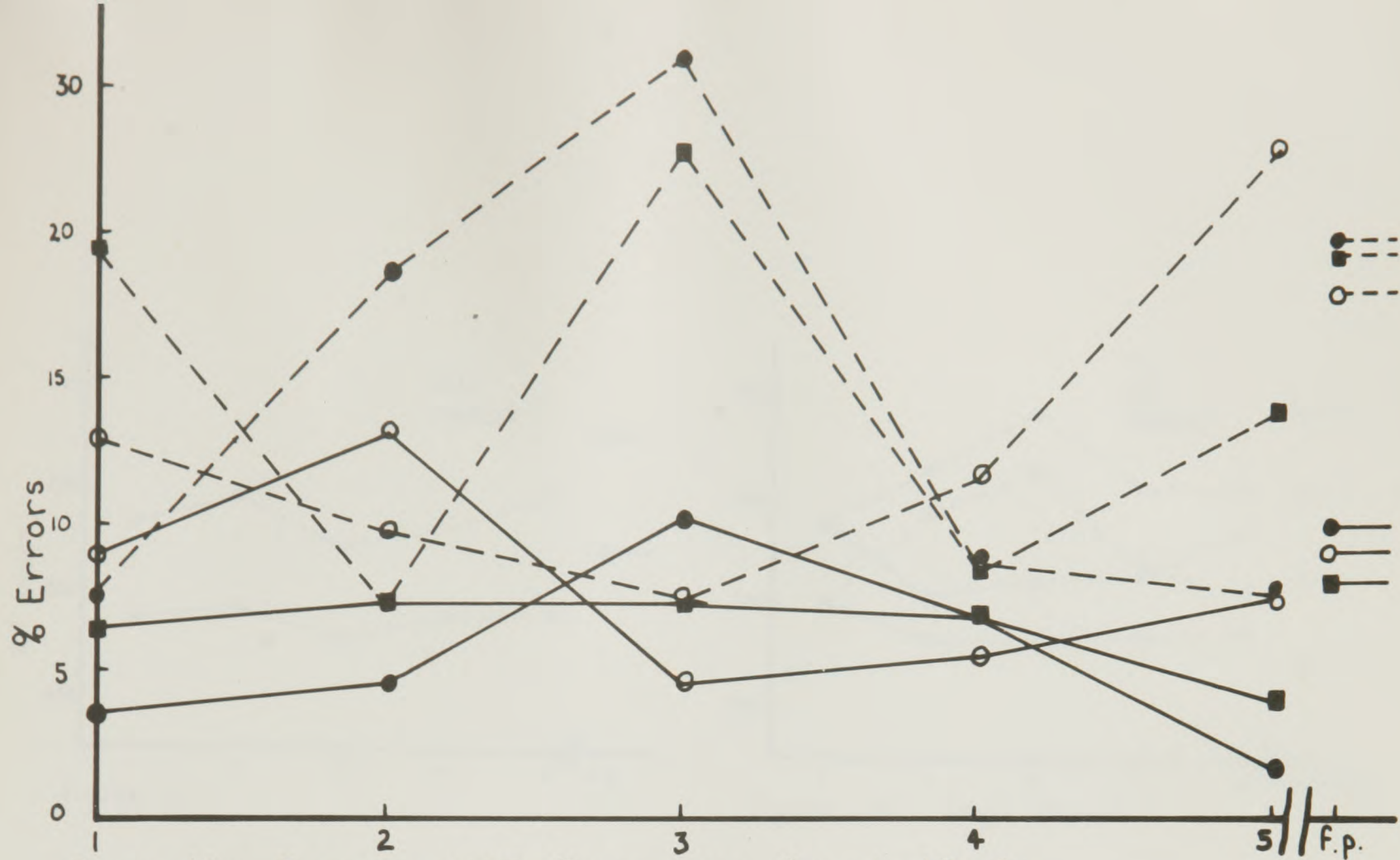


Figure 10a. Experiment VII. Error rates for all 12 Ss.

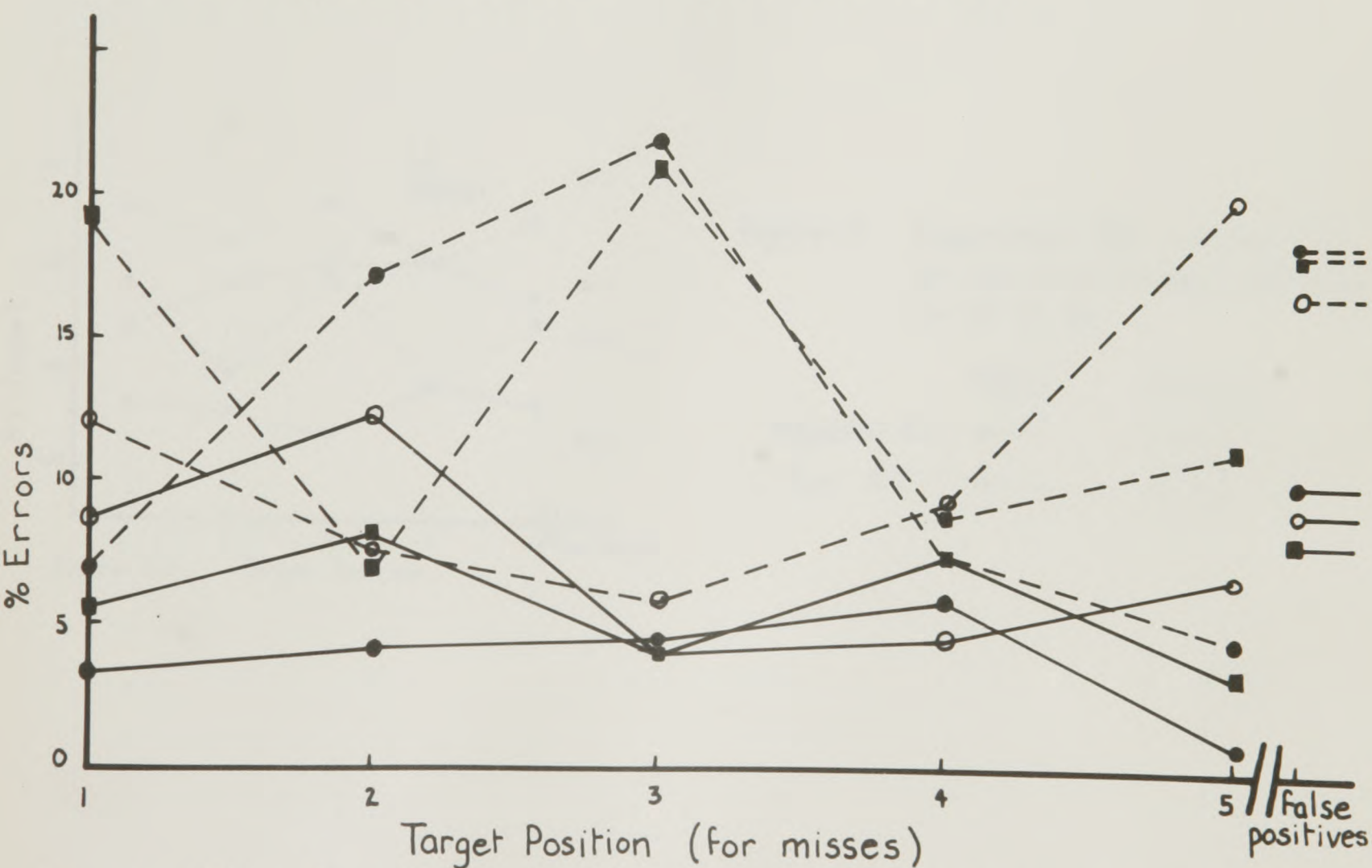


Figure 10b. Experiment VII. Error rates for 11 Ss (E.J. omitted).

	Speed	Accuracy
<u>sm</u>	○-----	○-----
<u>nb</u>	●-----	●-----
<u>bl</u>	■-----	■-----

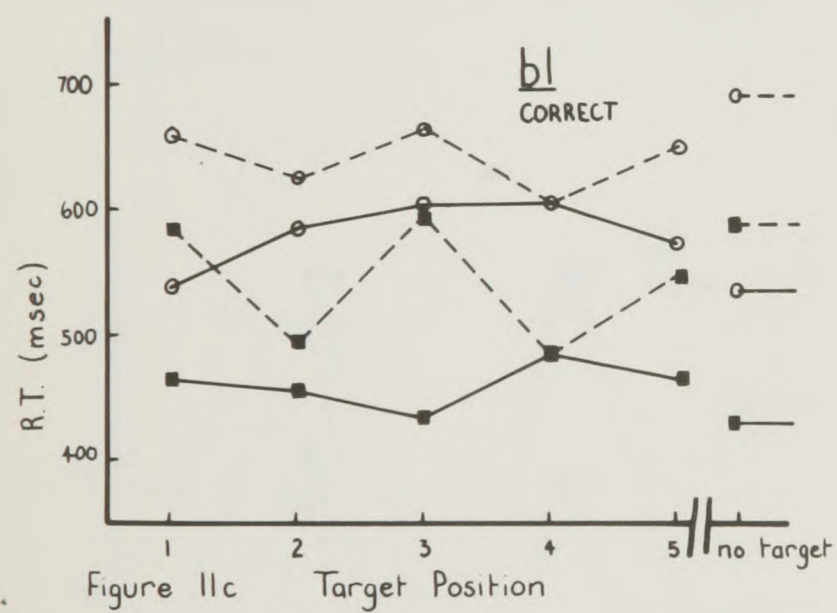
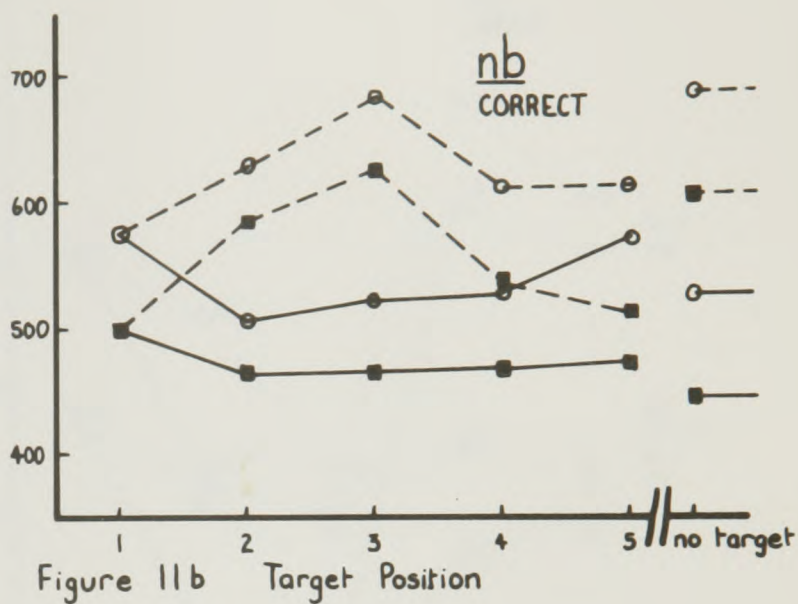
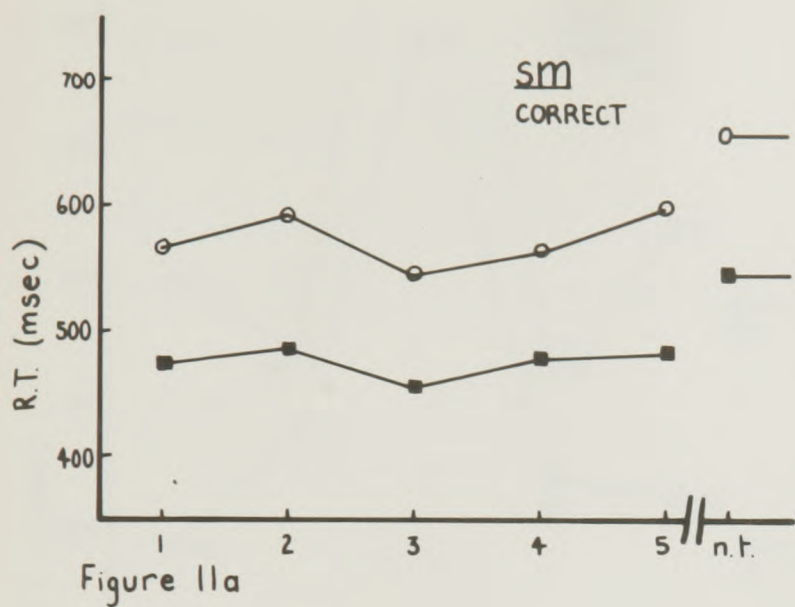


Figure 11. Experiment VII. Correct R.T.s for the three display conditions, for all 12 Ss.

	Speed	Accuracy
Adjusted R.T.	■ —	○ —
Raw R.T.	■ - - -	○ - - -

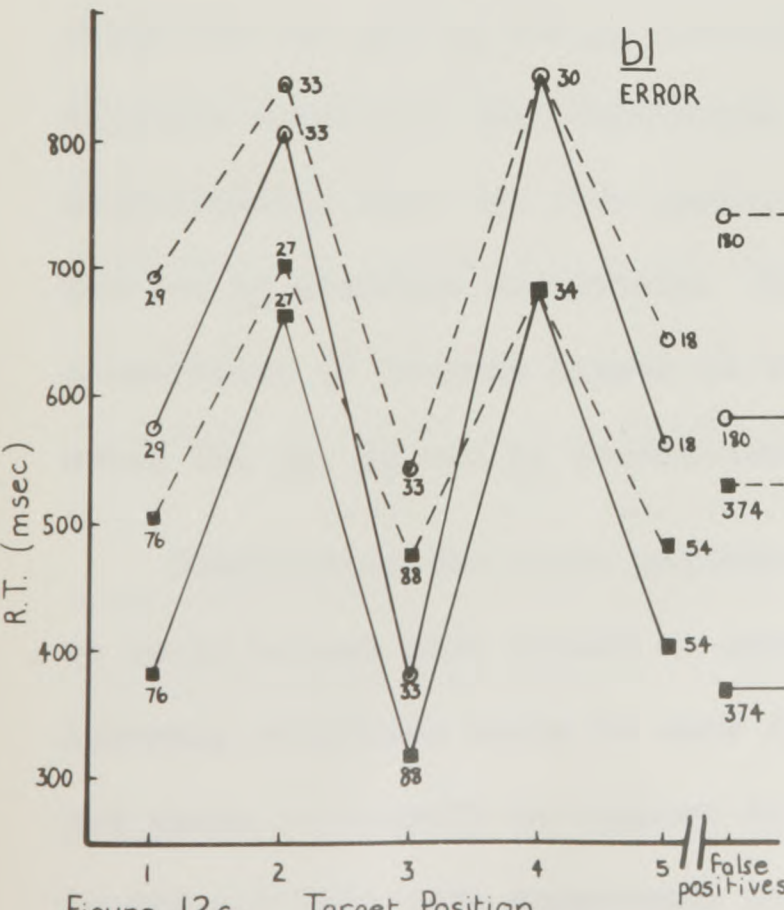
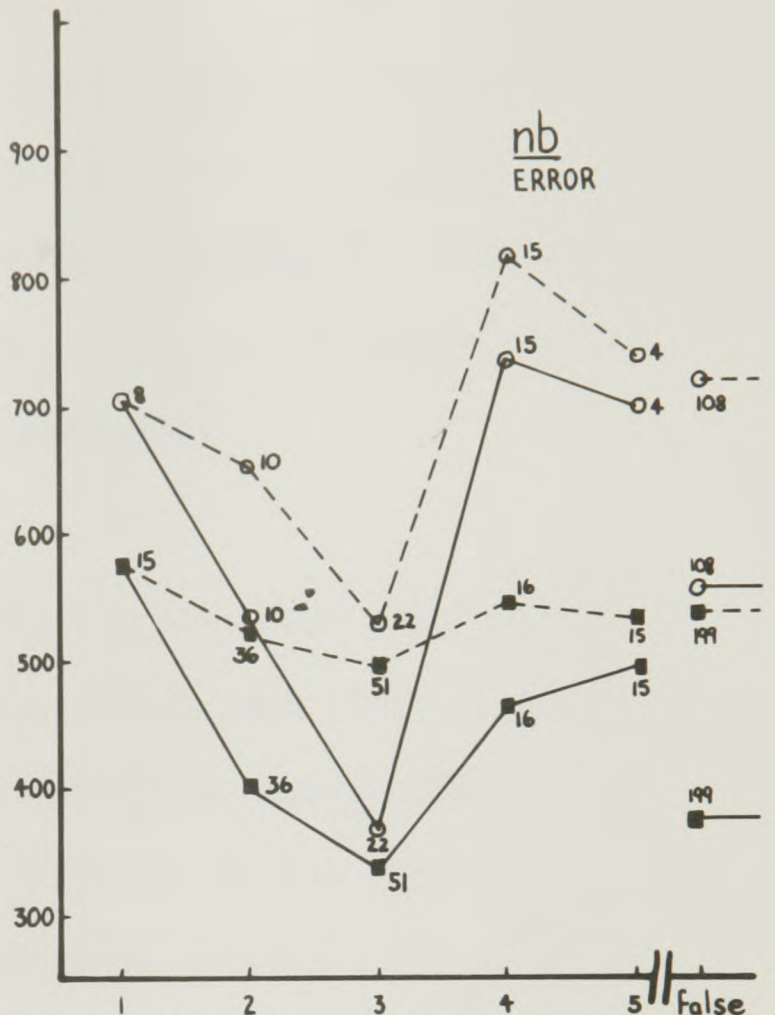
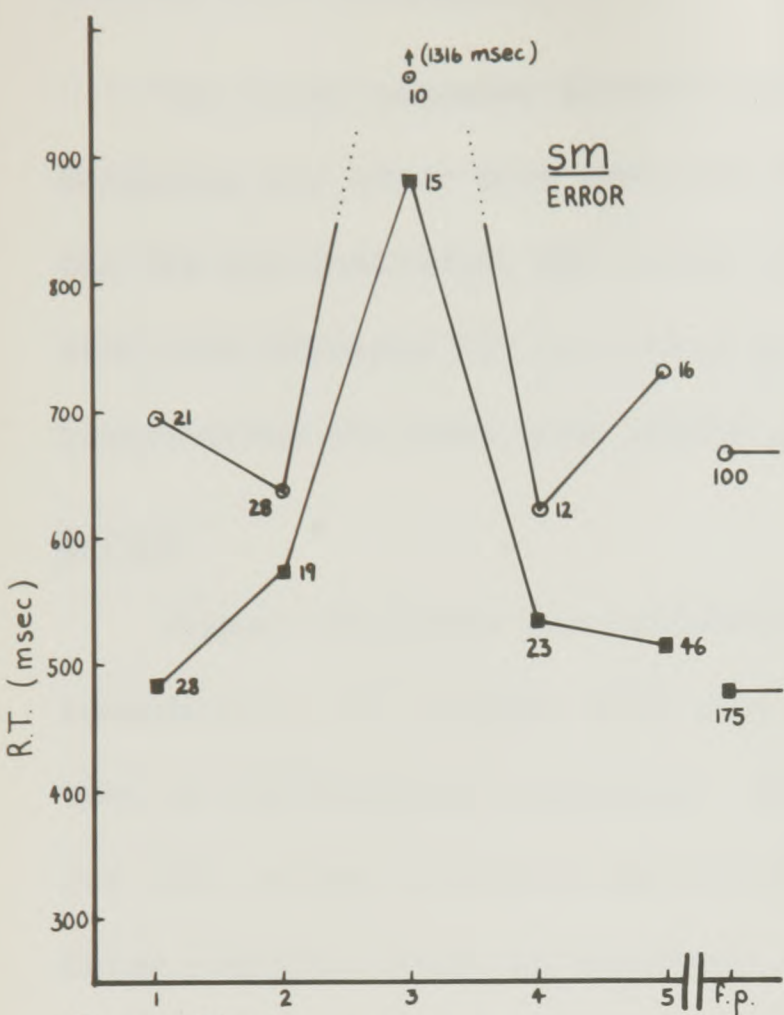


Figure 12. Experiment VII. Error R.T.s for the three display conditions, for all 12 Ss.

	Speed	Accuracy
Adjusted R.T.	■ —	○ —
Raw R.T.	■ - -	○ - -

(The number of R.T.s contributing is shown beside each point.)

RESULTS AND DISCUSSION

The first response in each list, and the response immediately following any error were excluded from the analysis. Examination of the RTs for individual Ss showed that the mean Speed RTs were shorter than mean Accuracy RTs for every S ($p < 0.001$ in each case), so the bias instructions did have some effect on behaviour.

Errors

Figure 10a shows the proportions of errors made under the various conditions. It is clear that many more errors were made in the Speed than in the Accuracy condition; the difference was significant ($p < 0.01$) for both misses and false positives, for each of the three display types. False positive rates in the Speed condition (average 19%) were approximately double those in the Accuracy condition (average 8.8%). For neither the Speed nor the Accuracy condition did the false positive rates for the sm, nb and bl display types differ significantly. In the Accuracy condition the proportions of targets missed did not differ significantly over the five positions and this was true for sm, for nb and for bl displays separately. Averaged over the five positions, the proportions of targets missed in the Accuracy condition did not differ among the sm, nb and bl conditions.

Considering the error pattern shown by the M Ss in Experiment VI, we would expect that misses at positions 2 and 4 for bl displays in the Accuracy condition would be more frequent than those at other positions, but there is clearly no support for this suggestion. In other words, Ss did not miss more suppressed than other targets in the Accuracy condition.

Turning to the miss rates in the Speed condition, there was a strong tendency for targets presented in later positions displayed to be missed. This consideration cannot, of course, apply for the sn displays, and in that case there were no differences among the proportions of misses made at the different positions, except that significantly more misses ($p < 0.01$) were made in position 5 than in any other position. For the two display types for which SOA was 40 msec, the hypothesis tested was that the miss rate was greater for the last three positions presented than for the first two. This hypothesis arose from the interpretation that in Experiment VI the W Ss made more misses in the three last positions presented (positions 1, 3 and 5) than in the first two presented because they were working quickly. So for the bl condition, miss rates at positions 1, 3 and 5 were compared with those at positions 2 and 4, while for the nb condition, the comparison was between the miss rates at positions 2, 3 and 4 and those at positions 1 and 5. In each case the difference was in the expected direction and significant ($p < 0.01$). Since targets in the later positions presented were missed more frequently in nb as well as in bl displays and the two effects seemed comparable in size, there was no evidence that the W pattern of errors obtained for bl displays in the Speed condition was especially related to metacontrast, rather than simply having been produced by the sequential nature of the presentation of characters forming a display and the emphasis on speed of response.

Response times

RTs were expressed as raw RTs and as adjusted RTs, as in Experiment VI, and the values are set out in Figures 11 and 12. The main finding (see Figure 12c) was that, when suppressed targets were missed, the RT (considering either raw or adjusted RT) was longer than when targets in other positions were missed and this was the case ($p < 0.01$) for both Speed and Accuracy conditions. This result was probably not attributable to temporal order of presentation alone because, as Figure 12b shows, there was no tendency for misses at positions 1 and 5 (the first two positions presented in nb lists) to be slower than misses at other positions, in the Speed case, and no significant tendency in the Accuracy case. But the numbers of responses on which Figure 12b was based were small (the numbers beside the points indicate how many RTs contributed) and so any conclusion, particularly one accepting the null hypothesis of no difference, must be tentative. If the effect is accepted as being caused by metacontrast, then these data suggest no additions to the interpretation given earlier (see RESULTS AND DISCUSSION for Experiment VI). The only point to add is that the long RTs associated with S missing suppressed targets were observed both in the Speed and the Accuracy condition, whereas in Experiment VI they were observed only for the M Ss.

Estimation of d' and β values

Methods similar to those used in the previous experiment were used here to estimate d' and β values for individual Ss in the sm condition and in the bl condition for targets in positions 2 or 4 only. The first finding was that d' values were higher in the Accuracy than in the Speed condition ($p < 0.001$ for the sm values; $p < 0.025$ for the bl values). So there appears to be no support for the hypothesis that S detected suppressed targets more readily when working quickly because the proportion of such targets missed in the Speed condition was actually slightly higher than that in the Accuracy condition and this, together with the much higher Speed false positive rates, led to the observed result that d' values were lower in the Speed condition. No β differences were obtained in these comparisons of the Speed and Accuracy conditions.

Comparison with Experiment VI

In the previous experiment the different patterns of performance shown by the M and W Ss could largely be interpreted in terms of biases for accuracy and speed respectively. Comparing the results of the two experiments there was indeed a close similarity between the performance of the W Ss in Experiment VI and that in the Speed condition of this experiment. In both cases average RTs were short, false positive and miss rates were high and there was a marked W pattern of miss rates over the 5 positions. Also, in the Speed condition, the mean correct RT was longer ($p < 0.001$) than the mean error RT and this difference was found for the W Ss of Experiment VI. Averaged over SOA values of 20, 30 and 40 msec, the miss rate for the W Ss was 28%, the false positive rate was 26% and the mean correct adjusted RT was 396 msec.

The corresponding values for the bl, Speed condition in the present experiment were 14%, 19% and 399 msec respectively. So, although patterns of performance in the two cases were similar, Ss worked rather more accurately but just as quickly in the Speed condition of the present experiment as did the W Ss in Experiment VI. There is, however, one marked discrepancy between the two patterns: in the Speed condition, RTs were longer when suppressed targets were missed than when other targets were missed, but this was not so for the W Ss in Experiment VI.

There is not such a clear similarity between performance in the Accuracy condition of the present experiment and that of the M Ss in Experiment VI. In both cases RTs were long, error rates generally low, and error responses slower on average than correct responses ($p < 0.001$ for the Accuracy condition of the present experiment). In both cases, also, RTs were longer when suppressed targets were missed than when other targets were missed. But there was no sign of an M pattern of miss rates over the five positions, for the bl, Accuracy condition in the present experiment, to correspond with the M pattern shown by the M Ss at SOA = 20, 30 and 40 msec in Experiment VI. Also, averaging over SOA values of 20, 30 and 40 msec, the miss rate for M Ss in Experiment VI was 25%, the false positive rate was 17% and the mean correct adjusted RT was 536 msec. The corresponding values for bl, Accuracy condition in the present experiment were 6.5%, 9% and 567 msec, so Ss worked no more slowly but considerably more accurately in the latter case.

Some general comparisons between the d' and β values obtained in the two experiments were made. Considering all Ss in each experiment for the sm conditions only, the d' values in the Accuracy condition of the present experiment were greater ($p < 0.01$) than those in Experiment VI, but there was no significant difference for the Speed values. The β values for the Speed condition were lower ($p < 0.05$) than those in the previous experiment, indicating that Ss were biased more towards giving target present responses in the present experiment. There was no significant difference for the Accuracy values.

Comparisons were also made for the detection of targets in positions 2 or 4 in the bl condition of the present experiment and in the 20, 30 and 40 msec SOA conditions combined for the previous experiment. d' values in the present experiment were greater than those for Experiment VI, and this was true not only considering those for the Accuracy condition ($p < 0.001$) but also those for the Speed condition alone ($p < 0.005$). There were no β differences.

There were differences between the tasks and procedures used in the two experiments, and these may have accounted for some of the performance differences noted above. In particular, the use of bonus payments, a single target for each S and a constant assignment of the two responses to the two keys for each S probably accounted for much of the general superiority of performance in the present experiment over performance in Experiment VI. If the use of bonus payments also increased the emphasis on accuracy, even in the Speed condition, then it is plausible that RTs were long when suppressed targets were missed in the bl, Speed condition of the present experiment, assuming that the interpretation of the similar long RTs shown by the M Ss in

Experiment VI (as being the result of difficult discriminations) was correct. Considering this argument, and the comparative error rates, mentioned above, the W Ss of Experiment VI may reasonably be described as having worked quickly, while the M Ss of Experiment VI may better be described merely as slow, rather than accurate.

Data for Individual Ss

Examination of the data for individual Ss suggested that consideration of only the pooled data is not misleading except on one important point. Every S worked faster and made more errors in the Speed than in the Accuracy condition and in the Speed condition no S showed a pattern of errors markedly different from the mean for all Ss. For seven Ss the mean Speed correct RT was longer ($p < 0.01$) than the corresponding error RT, for three Ss there was no significant difference, while for two Ss (G.H. and J.H.) the difference was significant ($p < 0.01$) and in the other direction. In the Accuracy condition, the mean error RT was longer ($p < 0.01$) than the correct RT for nine Ss, there was no difference for one S, and the difference was reversed ($p < 0.01$) for two Ss (E.J. and V.N.). So the results for most individuals were similar to those for the group. The one exception was the pattern of misses shown in the Accuracy condition. As expected, the Accuracy error rate was low and so the group pattern may have been unduly influenced by one or two Ss making allarge number of errors, and just this appears to have occurred. The patterns of misses made in the Accuracy condition by two or three Ss tended more to that shown by Ss in the Speed condition. If, for example, the

data for E.J. were removed from the Accuracy analysis the mean error rates appeared as shown in Figure 10b. The selection of data may be partially defended in this case by observing that E.J. was one of the two Ss for whom mean Accuracy error RT was shorter than correct RT, that she made more misses than any other S in the bl, Accuracy condition and that of the 12 Ss she showed the smallest difference (49 msec) between mean correct Accuracy RT and mean correct Speed RT. She missed no suppressed targets in the bl, Accuracy condition, but missed a total of 26 targets from positions 1,3 and 5 in that condition. Comparison of Figures 10a and 10b shows that the omission of all E.J.'s data from the analysis did not alter the Speed curves, nor the sm, Accuracy curve very much. But the nb, Accuracy curve was changed in shape somewhat, and the bl, Accuracy curve changed markedly in shape from being nearly flat to showing the M shape originally observed for M Ss in Experiment VI. If each of the tests for differences mentioned when Figure 10a was being discussed is applied to the data for 11 Ss shown in Figure 10b, the conclusion is the same in every case and, in particular, the miss rates at positions 2 and 4 of the bl, Accuracy condition are still not significantly greater than those at positions 1, 3 and 5. (The data for 2 more Ss who gave short RTs and showed speed-like error patterns must be omitted before this difference reaches significance.)

Appearance of the displays

For the reasons given when Experiment VI was being discussed, no formal questioning of Ss about the appearance of the displays was carried out. However all Ss volunteered at least some comments. Nine of the 12 Ss said that the target letter 'jumped out' from the background letters, or that the background letters were 'there, but not seen' or 'blurred'. Similar observations are commonly made in visual search tasks (Neisser, 1966), but in this experiment Ss were making these observations in their first or, at the latest, in their second session of practice. Five Ss volunteered after a bl list that they could see only three letters, spaced out, in each display; one S said that she could find no pattern to the display in any non-simultaneous case. Perhaps the most interesting observation was that offered by one S when he said, after the bl list in his second session, that he never saw letters in positions 2 or 4 unless the target was there, in which case it still 'jumped out' and he saw it clearly.

Summary

In this experiment Ss' bias for speed or accuracy was manipulated and the observed patterns of performance were, on the whole, consistent with the performance expected of Ss working particularly quickly or accurately. Performance was generally superior to that in the previous experiment and error rates, particularly in the Accuracy condition, were low. No evidence was found in support of the hypothesis that suppressed targets are discriminated more efficiently from background letters if S responds quickly. Comparison of results of this and the

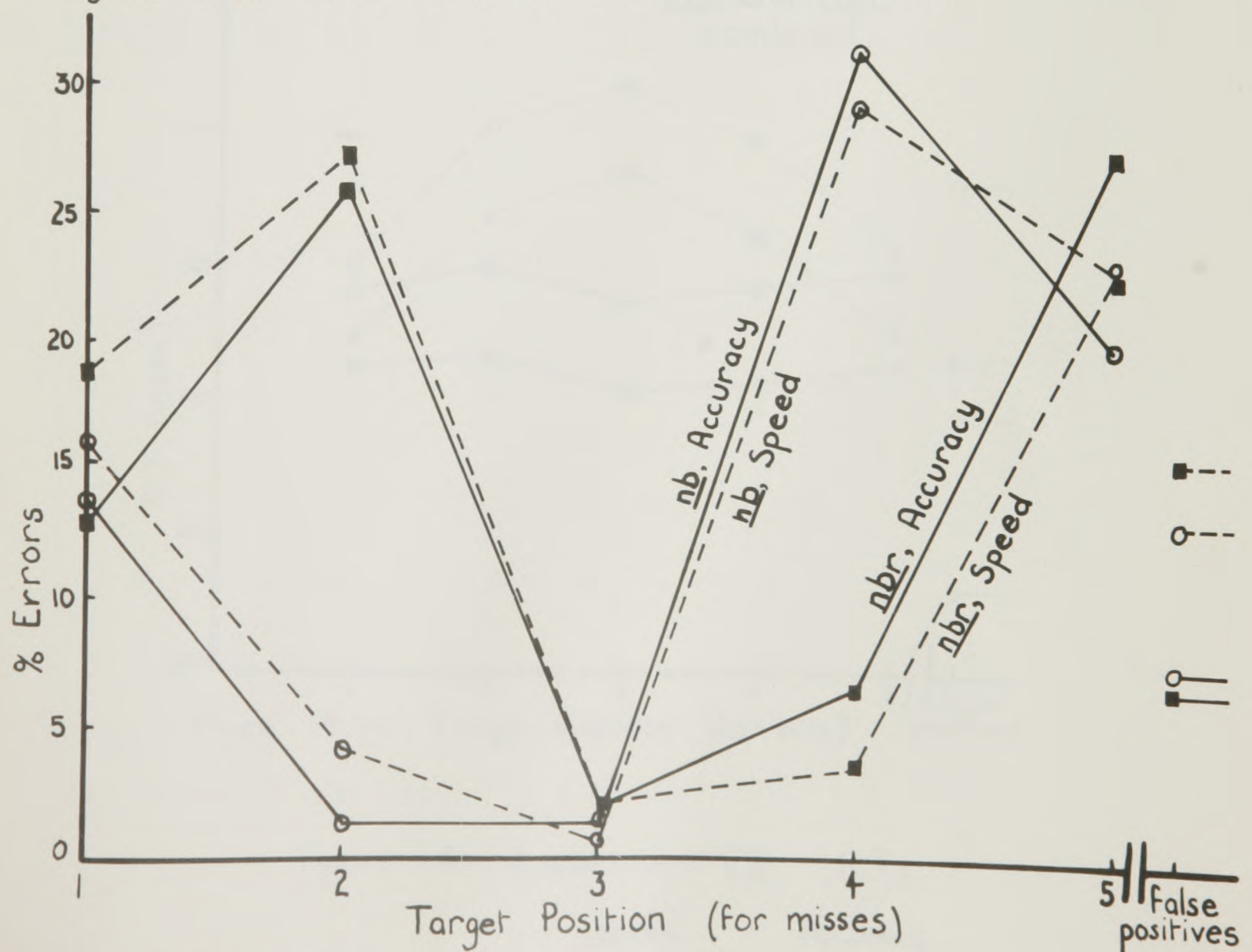
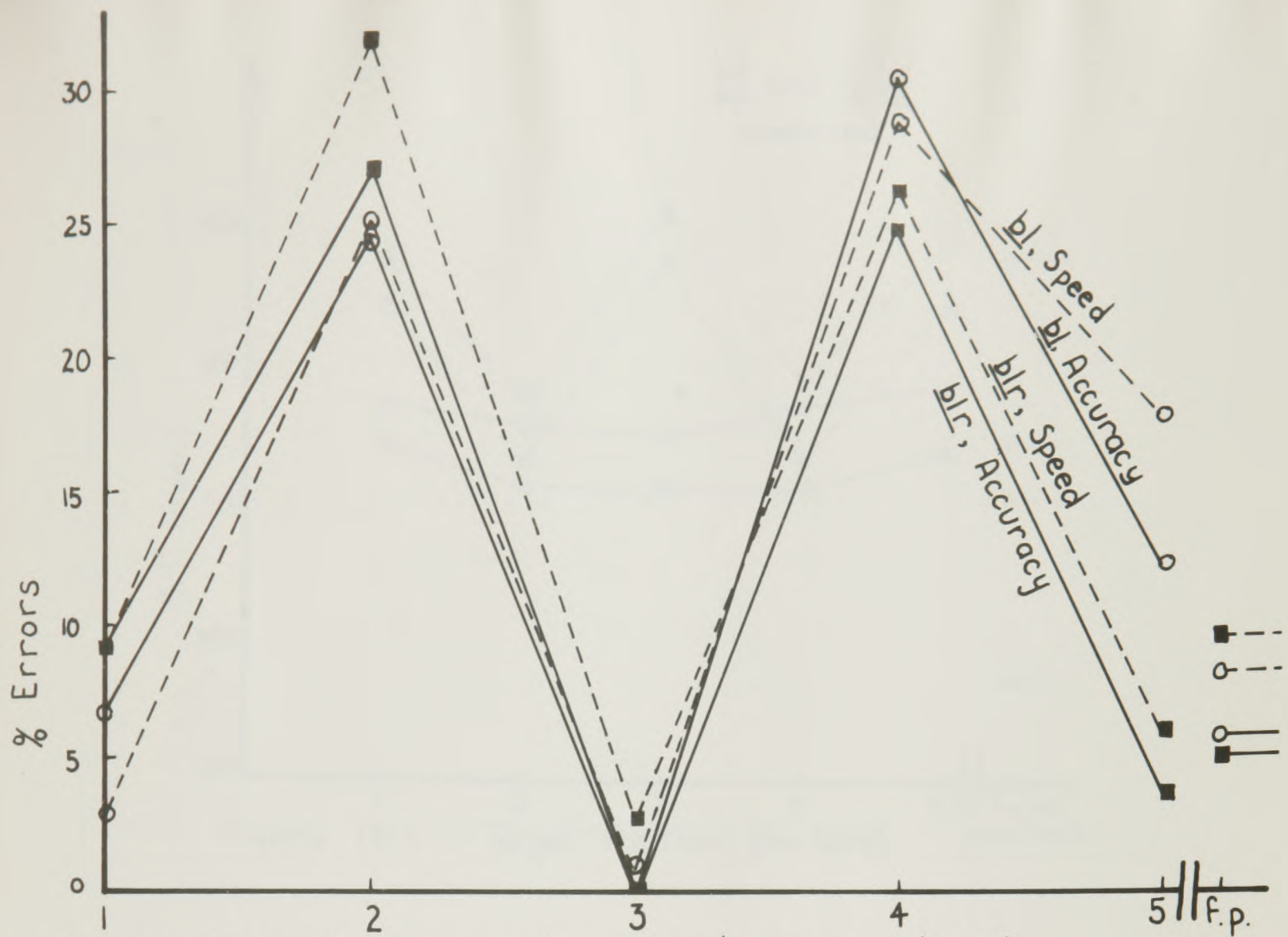
previous experiment suggested that the description of the W Ss as having adopted a set for speed was reasonable, but that the performance of the M Ss was better described as slow, rather than accurate. The W-shaped error curves seemed adequately explained as being a simple consequence of sequential presentation and a bias towards fast responding. It is possible that in the present experiment an M-shaped error curve was not observed in the bl, Accuracy condition because the error rate in this condition was only just above a floor level and also because the curve was contaminated by a relatively large number of errors contributed by a few Ss showing speed-like performance. But it may be that the emphasis of the whole discussion on biases for speed and accuracy has been misleading and that it would be more helpful to concentrate on response biases. One of the highly significant ($p < 0.005$) differences between the M and the W Ss in Experiment VI was that the W Ss, whose performance was speed-like, had lower criteria than did the M Ss i.e. their response bias was more towards target detection. Comparison of the β estimates for the two experiments showed that the median values for the present experiment were consistently lower than the medians for Experiment VI for all the various sm and bl conditions. Several of these differences were beyond the 0.10, two-tailed level, but just one was significant and that was the comparison mentioned earlier: β values in the sm, Speed condition of the present experiment were lower than those for the zero SOA condition of Experiment VI ($p < 0.05$). In addition, the overall bl β values for the M Ss of Experiment VI were greater

($p < 0.05$) than the β values in the bl, Speed condition of the present experiment. So there is a consistent suggestion in the results of these two experiments that success in discriminating suppressed targets from background letters is related to a low, lax criterion i.e. a response bias towards target detection. This would suggest that such targets may be detected if partial or dubious evidence for a target is accepted and so the hypothesis is consistent with the idea that in metacontrast some evidence is available and then lost. The similarity of the bl and nb miss rates in the Accuracy condition suggests that, given a sufficiently lax criterion, detection of suppressed targets can be very successful.

6.4 Go/no go Response and a strict Criterion

Experiment VIII : Visual Search with a Go/No go Response

In this experiment Ss once again searched for a single letter target in displays of random letters, but gave a go/no go response. In other words they used only a single response key and they pressed it only when they detected a target; if a display was judged not to contain a target S did not respond but merely waited for the next display to appear. As in the previous experiment Ss' biases for speed and accuracy were manipulated. The experiment was planned to add one more task to those studied in connection with metacontrast suppression and, by practically eliminating the possibility of making premature target absent responses, to estimate their importance in the previous two experiments.



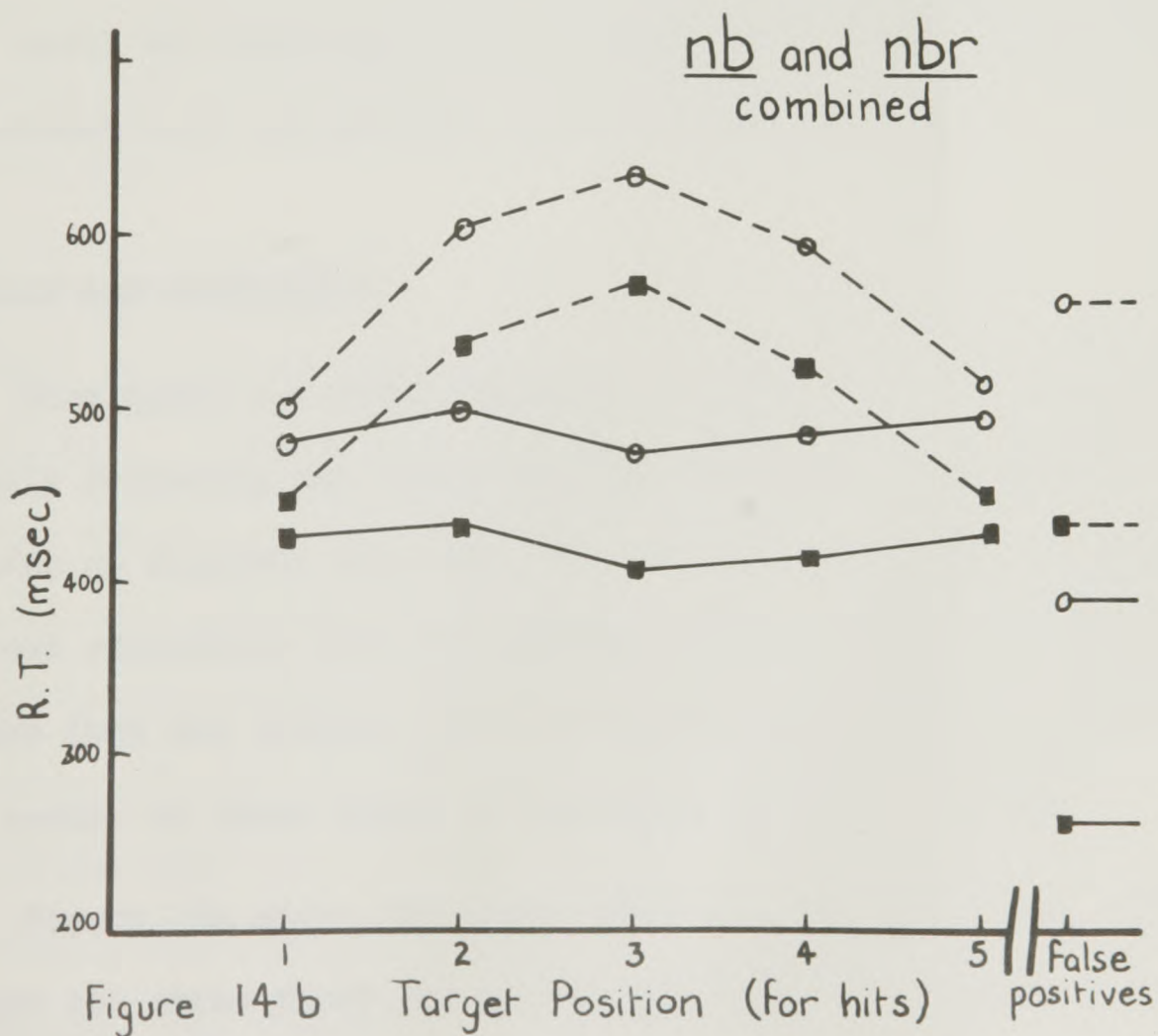
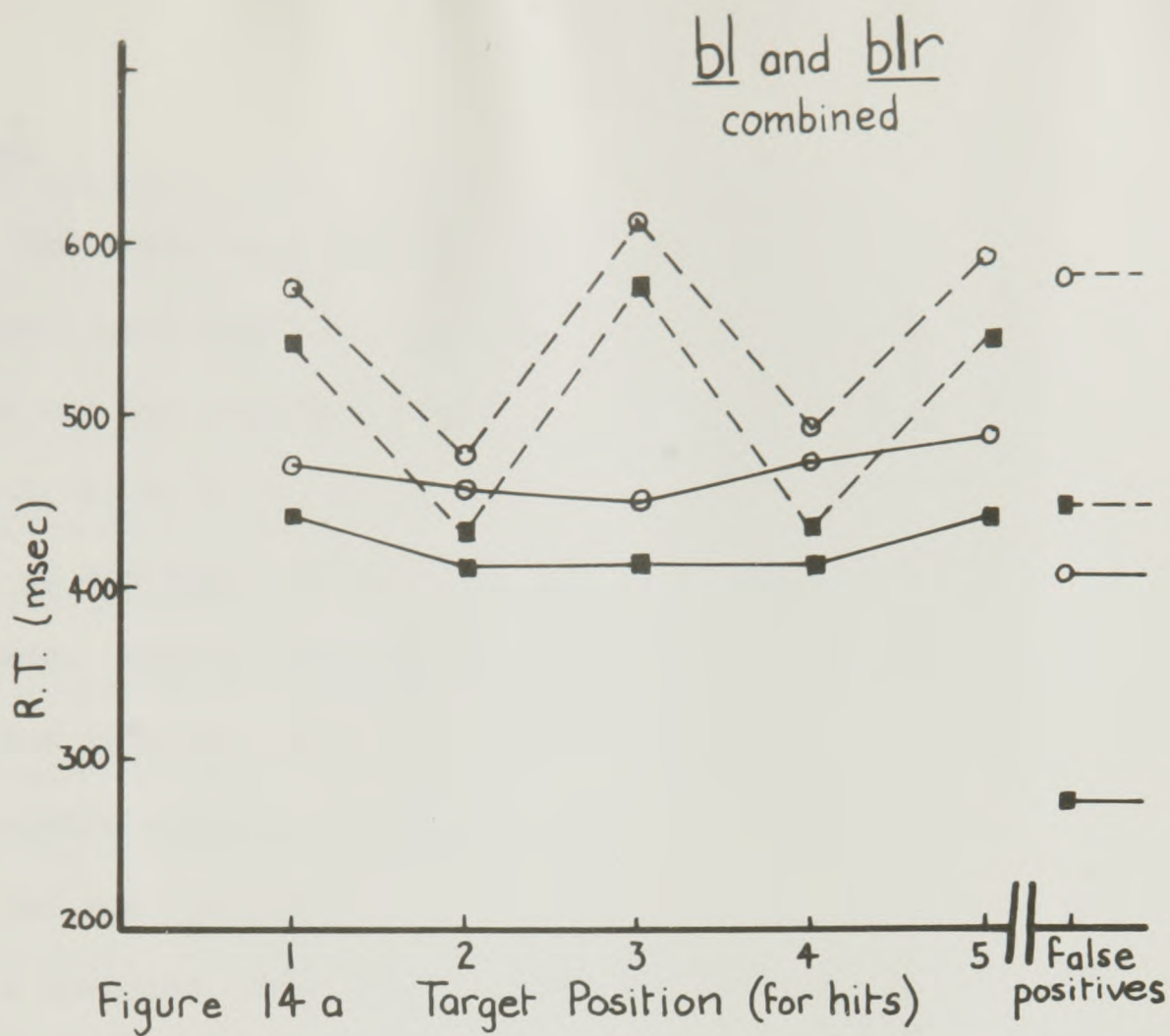


Figure 14. Experiment VIII. R.T.s

	Speed	Accuracy
Adjusted R.T.	■ —	○ —
Raw R.T.	■ - -	○ - -

METHOD

The eight experimental and one practice list prepared for Experiment VII were used again in this experiment. Eight Ss served, each for one Speed and one Accuracy session. The eight targets used, one for each S, were B, G, H, J, L, N, P and S. The display conditions used were bl, blr, nb and nbr, and one list in each condition was presented in each session. Letter presentation time was 20 msec and SOA was 40 msec. The S-S interval was 2 sec and the TSCOPE parameters were set so that successive displays appeared every 2 sec whether the single response key had been pressed or not. Ss were instructed to press the key with their dominant index finger when they detected a target and only then; if a display was judged not to contain a target they were simply to wait until the next display was presented. Other details of the experiment were the same as those in Experiment VII.

RESULTS AND DISCUSSION

Once again the first response in every list and the response immediately following any error were excluded from the analysis. Because a go/no go response was used, RTs were not, of course, obtained for correct rejections (key not pressed when no target presented) or for misses (key not pressed when the display did contain a target); only the number of these types of responses could be recorded.

Figure 13a shows the error rates for the bl and blr lists and Figure 13b shows those for nb and nbr displays. There were no differences between the curves showing miss rates in the Speed and

in the Accuracy conditions, for any display type. False positive rates in the Speed and Accuracy conditions were different overall ($p < 0.05$) and for the nb and nbr lists ($p < 0.01$), but the difference was not significant for the bl and blr lists alone. So it appears that in the Speed condition Ss worked a little faster and made more false positives, but missed as many targets as in the Accuracy condition. There is certainly no evidence to support the hypothesis that more suppressed targets are detected if response is initiated very soon after the onset of the display.

Figures 14a and 14b show the mean RTs for the bl and blr, and the nb and nbr displays, respectively. No differences were discernible between the bl and blr RTs, or the nb and nbr RTs, so only the combined means are shown in each case. In both cases the adjusted RT curves were close to flat.

As in previous experiments, no specific request for description was made, but all Ss volunteered some comments about the appearance of the displays. There was no consensus as to which display order or orders were the easiest or most difficult. One S said that all display orders appeared very similar. No S mentioned that any letters appeared missing from nb or nbr displays, but six Ss described bl or blr displays as consisting of only three letters, spaced apart. Two of these Ss went further and said that in these displays they never saw any letters at positions 2 and 4 unless a target was presented there, in which case it was visible, and 'leapt out'. One of these Ss, whose target was J, noted that occasionally an I or a T, which he found visually confusing with his target letter, also occasionally 'leapt out' from position 2 or 4.

Seven of the 8 Ss made comments such as 'Slowing down doesn't seem to help; I make just as many errors', indicating that they did not feel that their accuracy was very different in the Speed and Accuracy conditions. Examination of the data for individual Ss showed that the mean accuracy RT was longer ($p < 0.01$ or better) than the mean Speed RT for every S. The mean difference was 73 msec, but the corresponding mean difference between Accuracy and Speed RTs for Experiment VII, considering only RTs for hits and false positives so that the figures were comparable, was found to be 110 msec. The difference was barely significant ($p < 0.10$, two-tailed) but suggested that the differentiation between Speed and Accuracy performance, assessed by RTs, may not have been as marked in the present experiment as in Experiment VII. Perhaps this is plausible considering that in a go/no go situation S should do nothing on about half the trials and exhortation that he do so as fast as possible has rather a hollow ring to it, although there seems to be no logical reason why he should not be able to respond more quickly when he does respond. Indeed, he does so, but the difference may not be as great as that obtained with a two keypress response choice.

The first unexpected result of this experiment was that so many (28%) of the suppressed targets were missed. Figure 13a shows a clear M-shaped curve for the proportions of misses at the five positions. This curve is similar to that for the M Ss in Experiment VI and that for the bl, Accuracy condition (with E.J. omitted) in Experiment VII, yet the M-shape was obtained in both the Speed and Accuracy conditions of the present experiment. One aim of this experiment was to remove

the possibility of premature target absent responses and so to allow the 'underlying' pattern of misses in the Speed condition to be examined.

The result was not only that the Speed pattern, as well as the Accuracy pattern, became definitely M-shaped, but the proportion of suppressed targets missed was much higher than it had been in either the Speed or the Accuracy condition of Experiment VII.

Estimates of d' and β values were calculated for individual Ss in the various conditions so that comparisons could be made with the previous experiment. No systematic differences in d' values were observed but it was clear that the β values in the present experiment were higher than those in Experiment VII. The difference was consistent over display conditions, but individual variation among Ss was too great to allow any of the comparisons, which necessarily were between different groups of Ss, to reach significance. Median β values in the b1 condition of Experiment VII were 0.85 (Speed) and 0.64 (Accuracy) for data averaged over all five display positions, and 0.53 (Speed) and 0.69 (Accuracy) for data for positions 2 and 4 only. The corresponding values for the present experiment were 2.4 and 2.1, and 2.2 and 2.5 respectively. This analysis may even have underestimated the difference, because in the present experiment the false positive rates, especially in the Accuracy condition, were so low that a 'floor' may have been reached. If so, then the β values given may be substantially too low because β increases very quickly with small decreases in FAR, when FAR and H_R values are near those obtained in this experiment. It seems plausible that there is a minimum to the false alarm rate which may be obtained in practice; for example there will probably always be the occasional fast motor set, or 'muscle twitch', errors.

Some evidence that this may indeed have been the case in the present experiment was given by a comparison of the RTs obtained in this and the preceding experiment. Comparison of Figures 14a and 14b with Figures 11c and 11b showed that the adjusted RTs for the detection of targets in this experiment were somewhat shorter than the corresponding RTs in Experiment VII and the average differences were 27 msec for Speed and 60 msec for Accuracy. But comparison of Figures 14a and 14b with Figures 12c and 12b showed that the adjusted RTs for false positive responses in this experiment were considerably shorter than the corresponding RTs in Experiment VII and the differences were 62 msec for Speed and 188 msec for Accuracy. The difference between the differences was significant ($p < 0.01$ or better) in each case, i.e. for Speed, the 62 msec difference was greater than the 27 msec difference and for Accuracy the 188 msec difference was greater than the 60 msec difference. So the few false positive responses given in the present experiment were especially fast and, therefore, may well mainly have been inevitable muscle twitch errors and indicate that the false positive rates were near some minimum level.

With the advantage of hindsight it is plausible that the use of a go/no go response should result in a strict criterion. In Experiments VI and VII Ss may have regarded the task as a forced-choice task in which he was required to press one of the two keys and so he made his best guess and responded. In the present experiment S chose not between two keys but between action and inaction and he may have committed himself to a keypress response only when he was fairly sure that a target had been presented.

Suppressed targets presumably offer poor evidence for target detection and so if β is increased it should be the hit rate for these targets that drops. Comparison of Figures 13a and 10b showed that the proportion of suppressed targets detected in the present experiment was much lower than that for Experiment VII, while the average detection rates for targets in positions 1, 3 and 5 were the same in the two experiments. Experiments allowing comparisons within Ss between forced-choice response with two alternatives and go/no go response are required to settle the point, but, in the absence of reasonable competing explanations, the results do suggest that Ss in the present experiment were induced by the nature of the task to adopt a strict criterion and as a result they missed many suppressed targets. This hypothesis is similar to that proposed at the end of the discussion of the previous experiment after the results for Experiments VI and VII had been compared.

The interpretation given above does not distinguish between the Speed and Accuracy conditions, but it may be sufficient to note that, with the go/no go response used in the present experiment, S could have changed a fast, incorrect target absent response into a target detection response simply by changing his decision and pressing the key, so it is reasonable that the observed hit rates in the Speed and Accuracy conditions were the same. This argument does not, of course, apply to false positive responses and in this case the Speed and Accuracy error rates were indeed different.

Another unexpected finding was that so many targets were missed in the nb and nbr displays. Targets in position 4 of nb displays and position 2 of nbr displays were missed as frequently as suppressed targets in bl and blr displays, and once again the proportions were the same in Speed and Accuracy conditions. Also, targets in positions 1 and 5 in the nb and nbr displays were missed more frequently ($p < 0.05$) than those in the bl and blr displays, although less frequently ($p < 0.025$) than suppressed targets in these displays. These observations might suggest that poor performance with suppressed targets arose because the effects of position (2 and 4) and of display order (first and second) were simply summed and in the nb and nbr displays the effects were seen separately: performance at positions 2 and 4 and at the first and second positions presented (positions 1 and 5 for nb and nbr) was intermediate between that for suppressed and unsuppressed targets in the bl and blr displays. It is more likely, however, that the poor performance at positions 2 and 4 in the nb and nbr displays was specific to the display order rather than to the display position, because in each of these display types targets at only one of the two positions were missed frequently and in each case it was the targets in the third position displayed. It may also be relevant that the third position displayed was adjacent to the second displayed in the nb (14532) and nbr (23541) orders, and these were the only cases in these experiments in which successive characters appeared at adjacent positions. Even so, it is not at all clear why adjacent, successive presentation should have been especially difficult. It is possible that letters in the third position displayed were partially suppressed, since an adjacent letter, that in the central position, was displayed 80 msec later.

Comparison of results for the nb and nbr conditions with those for the bl and blr conditions of the present experiment showed that there were no discernible d' or β differences. So Ss' criterion was high for the nb and nbr lists also and the high criterion presumably must account for the different pattern of miss rates found in the nb, Accuracy condition of Experiment VII and in the nb and nbr conditions of this experiment. Many targets were missed in this experiment from positions 1 and 5 and, in particular, from the third position displayed, whereas in the previous experiment Figure 10 shows that the error curve was almost flat. It is only restating the results to say that targets at, in particular, the third position displayed in nb and nbr displays must have been in some way difficult to recognise or to distinguish from adjacent characters and were therefore often missed when S adopted a strict criterion. The difficulty does not seem to be simply metacontrast, because observers do not describe nb and nbr displays as missing characters; it may be related to the apparent movement seen in these displays. The results from the present experiment cannot take the argument beyond this rather unsatisfactory stage.

In summary, Experiment VIII gave no further evidence that suppressed targets may be detected more readily if an early response is made. It also offered no evidence requiring any change in the earlier conclusion that the W pattern of misses observed under some conditions in Experiments VI and VII was produced by premature target absent responses. The main finding of the experiment was that the strict criterion induced by the use

of a go/no go response resulted in many suppressed targets being missed, suggesting that Ss had only partial or dubious information for the presence of such targets. It remains a puzzle why so many targets were also missed from the third position displayed in nb and nbr displays.

CHAPTER 7

Letter Identification in Metacontrast

Experiment IX : Ss write down two letters in each display.

Many acoustic confusions are made in identifying suppressed letters, so these can sometimes be named, even if they are not always 'seen'.

Experiment X : Ss once again write down letters from displays of random letters. The fixation problem is solved, but not the problem of the identification of positions. Again more acoustic confusions are made to suppressed letters.

7.1 Introduction

The most natural way to start any study of the metacontrast suppression of letters may appear to be simply to ask S what letters are in a display and require him to guess the letters rather than just say that he sees nothing. This approach is appealing, but when it was tried three main difficulties were encountered. First, Ss were simply unwilling since they maintained that their confidence was so low and their guessing so wild that it was pointless to proceed. Second, either S was asked to name all the letters in the display, in which case the task was too difficult and memory factors intruded, or he was asked to identify only a few of the letters, in which case problems arose in choosing which ones. Finally, without apparatus for monitoring S's fixation direction, it appeared to be impractical to require consistent fixation anywhere but precisely at the display position of the suppressed letter to be reported.

Experiment IX took the direct approach and met all these problems head-on. Experiment X grew out of what had been intended as a series of pilot experiments to determine the most satisfactory conditions in which to investigate letter naming in metacontrast. In each case S saw a display of random letters and was required to write down some or all of the letters, guessing if necessary. Unlike the experiments described in the preceding chapters these two experiments were self-paced and did not place S under any time pressure, and the computer did not record any responses or measure RTs.

7.2 Letter Naming in Metacontrast

Experiment IX : Naming pairs of letters in displays of random letters

Ss used a foot-switch to trigger presentations of displays of five random letters. They were instructed to fixate on a central fixation spot before each presentation and to write down the letters in two specified display positions.

METHOD

Eight experimental lists of 50 displays and two practice lists of 20 displays were prepared. Each display consisted of five letters chosen randomly without replacement from the full alphabet. Display conditions used were sm and bl, with an SOA value of 30 or 40 msec, and were always constant within a list. Letter presentation time was 20 msec.

The response keys were removed and a response booklet provided for S, positioned so that he could write in it comfortably and preferably without removing his face from the rubber mask and looking down. A foot-switch was also provided and TSCOPE parameters were set so that displays were presented singly. When the foot-switch was pressed a dim fixation spot appeared in the centre of the screen and remained on till S released the foot-switch and so triggered the presentation of a display.

Eight of the 12 Ss who served in Experiment VI each served for one session in this experiment. S's task was to write down after each display the two letters occupying two specified non-adjacent positions in the display.

Report of two non-adjacent letters rather than a single letter was required in every case so that the task was difficult and so that the possible benefit of selective fixation would be reduced. Report of two letters rather than all five letters was used so that the task was not too difficult and to reduce memory loss while S was responding.

S was instructed to initiate a trial by pressing the foot-switch, then to fixate the dim spot presented in the centre of the screen. When he had the spot clearly in focus he was to release the foot-switch to trigger the presentation of the next display and then write down the letters occupying the specified positions, guessing if necessary.

The task was self-paced and S was encouraged to work as accurately as possible. Display positions were simply numbered 1 to 5 from the left to the right and S was instructed to report the letters e.g. in positions 2 and 5. The two positions for report remained fixed for

the 50 displays in any list, but were changed from list to list. S knew that each display was made up of five different letters presented in five positions in a row in the centre of the screen, with position 3 defined by the position of the fixation spot. S was also instructed to write down the two letters in left to right order. If in doubt he had to guess and he was encouraged to guess the identity of the letter rather than make a position error by simply reporting a letter seen at a position adjacent to that specified for report.

Two practice lists, each of 20 displays, were used for each S, one immediately before his first sm list and one immediately before his first bl list. It was intended that each S work through six lists of displays, half being sm lists and half being bl lists, with no S seeing any single list more than once and with each of the eight lists available being used about equally frequently. But the task was self-paced and different Ss adopted quite different speeds of working, and so the total of six completed lists was not achieved by three of the eight Ss within reasonable limits set by time and the S's patience. Every S, however, completed approximately equal numbers of sm and bl lists, and positions 2 and 4, and positions 1, 3 and 5 were specified for report about equally frequently for each S.

RESULTS AND DISCUSSION

Before the results were examined or analysed the alphabet was divided into acoustically confusable sets. This was done subjectively, but independently of the results of this experiment, and after consideration of the analyses of acoustic confusions made by Conrad (1964) and Wickelgren (1965, 1966). The division adopted was (A J K), (B C D E G P T V), (F L M N S X), (H), (I Y), (O), (Q U), (R), (W), (Z), where two letters are considered to be acoustically confusable if and only if they belong to the same bracketed group.

Scoring the responses

In all, 19 sm lists, 10 lists with SOA = 30 msec, and 14 lists with SOA = 40 msec were completed. The response sheets were scored by hand. Each single letter was considered correct if it had appeared in the display in the position specified for report. If it had appeared in the display in another position it was termed a position error and if it had not appeared in the display it was considered to be an item error. The last 40 responses, each response being two letters, were scored for each list. This meant that responses for the first 10 displays in each list were considered to be warm-up and practice displays and were omitted from the analysis. In some lists an occasional display was missed because S did not release the foot-switch cleanly and so in those lists 7 or 8 responses were omitted, again leaving 40 responses for analysis.

Preliminary analysis revealed no discernible differences in error rates or error patterns between lists with SOA = 30 msec and those with SOA = 40 msec and so these results were pooled and these lists will be referred to simply as bl lists.

Ss' comments, and the results, suggested that Ss had some difficulty determining from which positions to report letters, probably largely because apparent movement made it difficult to assign letters to the positions, numbered 1 to 5 from left to right, but which were defined only relatively. Ss found the first few displays of each list particularly troublesome because they had to write down letters from a different pair of positions in each list; this reported difficulty was the main reason for scoring only the last 40 responses in each list.

During the scoring of the responses it became clear that in some cases Ss made the same position error consistently for most of the displays in a list. Such a consistent error may indicate that S assigned the letters to the numbered positions incorrectly, perhaps because of the apparent movement in the displays, or that he adopted a strategy of giving an adjacent letter from the display when in doubt (although this practice was discouraged). A consistent error was defined to have occurred if half or more of the 40 responses for a list contained the same position error (e.g. the letter presented in position 1 reported when position 2 was specified for report). Three of the eight Ss made one or more consistent errors, a total of six lists contained consistent errors and all of these were bl lists. Seven consistent errors occurred (one list contained two) and for five of them letters in one of the positions 1, 3 or 5 were consistently reported when positions 2 or 4 had been specified for report.

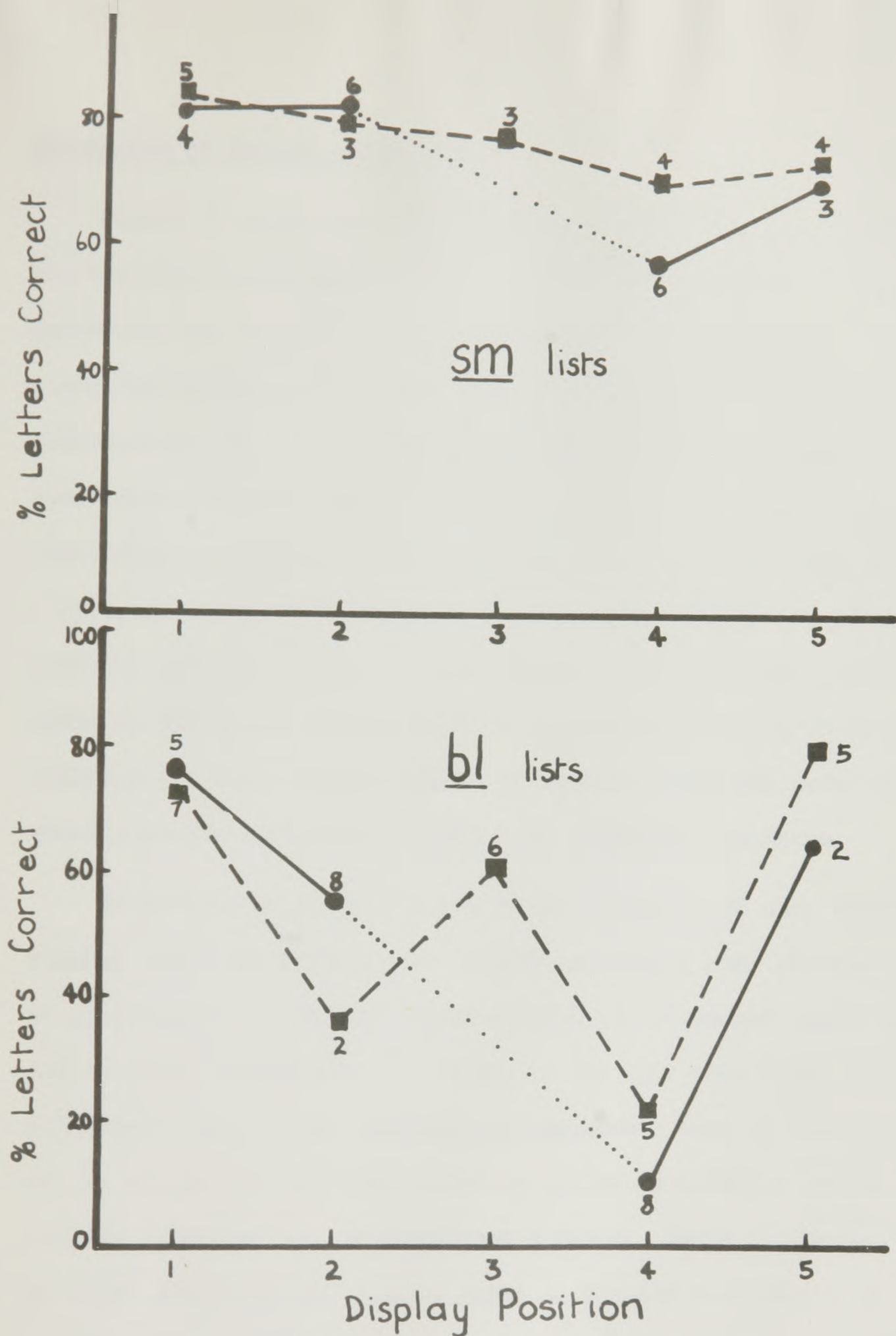


Figure 15. Experiment IX. Percentages of correct letters in the correct positions. The number of lists contributing to each point is shown beside the point.

● — : The other position for report was 2 or 4 .
 ■ - - : " " " " " " " 1, 3 or 5 .

Discussion of general performance

Figure 15 shows the percentage of letters reported correctly at the 5 positions in each type of display. Percentages are shown separately for cases in which a position was specified for report along with positions 1, 3 or 5 and cases in which the other position specified was 2 or 4. In the latter case there is no point shown for position 3, because the two positions specified for report were always non-adjacent and so position 3 was only ever specified with positions 1 or 5, and never with positions 2 or 4. No analysis of errors into position and item errors is given because many position errors probably arose because S did report adjacent letters when he was in doubt and the tendency for this to occur cannot be assessed from the data, and it may quite possibly have been different for different positions.

In general Ss found the task very difficult and some doubted seriously whether they ever could report letters correctly from positions 2 and 4 of bl displays. Although a fixation spot was presented before every display and specific instructions to fixate on the spot were given, every S maintained that it was virtually an impossible task to fixate exactly on the centre and yet concentrate on giving an accurate report of the letters presented e.g. in positions 2 and 5. Every S reported that for at least some displays in some lists he fixated voluntarily or involuntarily a little to one side of the centre. The usual strategy described for bl displays in which one of the positions 2 and 4 was specified for report was to fixate near position 2 or 4 and attend more to that letter than to the letter in position 5 or 1, the other letter to be reported. When both

positions 2 and 4 in bl displays were specified, Ss frequently said that they made little attempt to identify the letter presented in position 4, because it was so difficult to identify even one suppressed letter.

The results shown in Figure 15 are contaminated, therefore, with unknown effects of variation of fixation and strategies adopted by Ss. In particular, Ss probably traded accuracy between the two positions to be reported and so the differences shown in the figure between the points for positions 1, 3 and 5 and those for positions 2 and 4 are probably under-estimates. The results do show, in a general way, that in bl lists it was very difficult to report the letters in positions 2 and 4. Ss did, however, report the letter in position 2 relatively accurately when positions 2 and 4 were specified. This may indicate that selective attention to suppressed letters or to unsuppressed letters was easier than to one of each type, or that different analyses were required and it was difficult or time-consuming to switch between the two. Or, since the two suppressed letters were presented first, it might indicate that selective attention to one short time interval was better, or again, that spacing was important (2 and 4 were closer together than 2 and 5 or 1 and 4). But all these explanations would predict that performance with 4 would have been better than it was observed to have been when 2 and 4 were specified, so the comparatively good performance with position 2 in this case probably reflected the strategy of fixating in position 2 and giving relatively little attention to position 4 that Ss described. The result that letters in positions 2 and 4 of bl displays

were, in general, difficult to report still does not distinguish between the difficulty of seeing the letters and the difficulty of defining the positions. Also, positions 2 and 4 might be expected to have been the hardest to define, since the fixation spot defined position 3 and positions 1 and 5 were the ends of the display, but there was no similar direct reference point for positions 2 and 4. There is also no way of knowing why selective fixation was helpful if indeed it was, for it may simply have served to define a position rather than allow more accurate perception of the letter in that position.

In summary so far, there were many untidy aspects of the task required of Ss and many qualifications which must be made to any interpretation of the accuracy results shown in Figure 15. The second approach to the analysis of the results enquired whether there were other differences, besides those in overall accuracy, between performance with suppressed and other letters. One line of thinking followed from the hypothesis stated several times previously that information about suppressed letters may be available at first, but after a short time is removed. Since visual presentation is used the earliest form in which information about suppressed letters might be available is visual. If metacontrast operates soon afterwards by removing some form of visual or shape information it may be possible that recoding of the original information from a visual form into some deeper form could preserve it from metacontrast suppression, if the recoding could be carried out sufficiently rapidly. An obvious deeper form of coding to consider is name coding and so it may be instructive to analyse letters which were errors for their visual and acoustic confusibility with the corresponding correct letters.

Column Display type	(1) <u>sm</u>	(2) <u>sm</u>	(3) <u>bl</u>	(4) <u>bl</u>
Positions	1,3,5	2,4	1,3,5	2,4
Subject				
A.D.	2/14 (14%)	0/23 (0%)	1/14 (7%)	16/61 (26%)
R.D.	4/25 (16%)	1/15 (7%)	1/18 (6%)	8/43 (19%)
D.G.	2/26 (8%)	0/0 (0%)	4/23 (14%)	2/11 (18%)
S.G.	1/6 (17%)	2/13 (15%)	3/15 (20%)	2/24 (8%)
M.H.	0/13 (0%)	1/9 (11%)	0/12 (0%)	10/42 (24%)
I.L.	1/22 (5%)	6/33 (18%)	4/33 (12%)	7/47 (15%)
A.S.	0/8 (0%)	4/21 (19%)	1/13 (7%)	3/16 (19%)
S.W.	1/5 (20%)	4/24 (17%)	2/21 (10%)	8/32 (25%)
Total	9.2%	13%	10.2%	20.3%
Total without (C,G) and (M,N)	4.2%	3.6%	8.3%	20.3%

Table 9: The proportion of item errors for Experiment IX which were acoustic confusions, for different display types and different sets of positions, for individual Ss. The equivalent percentages are shown in brackets.

Acoustic confusions

The second analysis concerned the proportions of item errors which were acoustic confusions, i.e. which were acoustically confusable, as defined earlier, with the corresponding correct letters. All position errors were ignored and the proportions of the remaining errors, item errors, which were acoustic confusions were determined. They are shown in Table 9. Proportions were also examined separately for letters reported first and second but no differences were discernible. An analysis due to Cochran (see Maxwell, 1961, p. 77), which takes into account the varying numbers on which proportions are based, was applied to pairs of columns in Table 9. It showed that (4) was different from (1) and from (3) ($p < 0.025$), although the difference between (2) and (4) was significant only at the 0.05, one-tailed level (critical ratio = 1.35). No differences were apparent among the proportions shown in columns (1), (2) and (3).

While the response sheets were being scored it was noticed that some item errors which appeared to be visual confusions occurred fairly frequently, particularly in sm lists. If visual confusions were also acoustic confusions, then this tendency, if real, might hide any tendency for acoustic confusions to occur at suppressed positions. Scoring was interrupted and the letter shapes (see Figure 5) were examined for possible correlations between visual and acoustic confusibility. The two pairs (C, G) and (M, N) seemed to be the only pairs previously classified as acoustic confusions which might be very confusable visually as well. Indeed C and G, and M and N only differ by the

placement of two dots and the letters in all other acoustically confusable pairs are more different in shape than this. If the pairs (C, G) and (M, N) are no longer considered to be acoustic confusions, the proportions shown in the bottom row of Table 9 are obtained and tests on these proportions would clearly lead to the same conclusions as previously, but with higher levels of significance. This observation may increase the plausibility of the conclusions a little, even though some of the results had been examined before the change in scoring procedure was made. Examination of Figure 5 also suggests that pairs of letters within the same acoustic confusion group (see first paragraph of this section) are probably not markedly more or less visually confusable on average than pairs of letters from different groups.

There was no control over the time between display presentation and S's response, so it might be argued that difference in storage time may have produced differences in the proportions of acoustic confusions and, if the suppressed letters were indeed the most difficult to report, Ss may have hesitated longer in reporting suppressed letters, even though this would probably only have reduced their performance even further. This explanation is unlikely because, as mentioned previously, no difference was apparent between the proportions of acoustic confusions for letters reported first and second. Also, the 100 msec or so difference in storage time for suppressed and other letters produced by the sequential nature of the presentation is scarcely likely to account for the results.

The conclusion must be that relatively more item errors were acoustically confusable with the correct letters when letters were reported from suppressed positions than when they were reported from other positions in bl displays or from any positions in sm displays. Since acoustic confusions occurred when suppressed letters were reported, S must frequently have been able to extract sufficient information from the display to name the suppressed letter. Since the proportion of item errors which were acoustic confusions was smaller ^{for} ~~than~~ other, unsuppressed letters some additional form of information for response, besides name information, must have been available in those cases and this was presumably some kind of visual or shape information. When S reported suppressed letters, therefore, he must have relied on a name code relatively more frequently than when he reported other letters. Suppressed letters were initially only available in visual form, of course, but in addition the visual information originally available must have been lost.

It might be argued that visual information about suppressed letters may indeed have been lost but that the results do not require the conclusion that these letters could frequently be named, because the proportion of acoustic confusions for suppressed letters may be just that expected by chance, while the other proportions were lower because visual confusions predominated in these cases. But this argument rests on two unlikely assumptions. First, if S guessed randomly from the full alphabet when in doubt, the expected proportion of acoustic confusions is 0.148 and so a considerable bias towards guessing from the large acoustic confusion groups would be required to obtain by chance the observed proportion of 0.203.

Also, the argument assumes that, if the proportion of visual confusions increases, that of acoustic confusions must decrease and for this to occur pairs of letters from different acoustic confusion groups would have to be, on the average, considerably more visually confusable than pairs of letters within the same group.

It is interesting to note that the absolute level of performance with suppressed letters in this experiment (see Figure 15) was much lower than that in the visual search experiments (see Chapter 6). So, although suppressed letters may sometimes be named, the greater complexity of the letter identification task over the simple target/not target classification was reflected in the quite different levels of performance shown by the two experiments. The additional requirement in the present experiment that positions had to be identified no doubt contributed to the difference.

Summary

The task used in this experiment was a difficult one and in particular Ss found it impossible to maintain fixation as instructed and difficult to distinguish and number the five display positions (consider, for example, the large number of consistent errors made), as well as to identify letters which were suppressed. Nevertheless, a larger proportion of the item errors made when reporting letters at suppressed positions were acoustically confusable with the correct letter than was the case for other positions in bl displays or for any position in the sm displays. Two conclusions follow from this result. First, suppressed letters could sometimes be named and, second, visual information about these letters was lost more readily than that about other letters. Considering subjective descriptions

of displays in which letters are suppressed, this loss of visual information is presumably exactly what metacontrast suppression is. These conclusions fit well with our hypothesis that in metacontrast displays information about a suppressed letter is available at first and then lost. They add to the hypothesis by suggesting that the loss of information is a specifically visual loss and that letters may survive if they can be recoded sufficiently quickly into, for example, a name.

7.3 Naming letters: Attempts at better experimental control

Experiment X : Naming letters: Nine pilot experiments

Experiment IX suffered from uncertainty and confusion about the selection by S of the positions from which report was required and about just where S fixated. Numerous variations in the display and response conditions were possible and a series of pilot experiments was planned to find the conditions preferred by Ss and allowing the most direct study of errors made to suppressed letters. No very satisfactory set of conditions was found, however, and individual differences seemed too large to allow satisfactory selection of the best conditions from those which had been used, so some extra Ss were run in the last two conditions used and the results from all conditions analysed together. Nine sets of conditions were tried formally and these will be described as Experiments Xa, Xb, ... Xi. In every case S used a push-button to trigger presentation of a display, then wrote down some or all of the random letters in the display, guessing if necessary.

METHOD

Aspects of the apparatus and the method that were the same for all the experiments will be described first and then the individual experiments will be described.

Two aspects of the apparatus used in Experiment IX were improved for the present experiment. Ss found the foot-switch rather awkward to use and occasionally a display was incorrectly triggered and so was missed. A bistable micro-switch operated by a push-button and held in S's non-dominant hand was used instead. Ss also found it awkward to write their responses without taking time to move out from the rubber mask and look down at the booklet. So a device was built and mounted below the scope to allow S to write his response on a roll of paper positioned behind a small vertical window. An adjustable elbow-rest was provided and there was a sloping shelf just below the window for S's wrist. The window was just below the face of the scope and at the same viewing distance, so no change in convergence or accommodation was required when S looked down and wrote his response. This arrangement allowed S to control presentation with his non-dominant hand, write his response with his dominant hand and then pull down the strip of paper so that a blank piece was behind the window and ready for the next trial.

Lists consisted of 50 displays and each display consisted of 5 characters. The first two displays in a list were for warm-up and the remaining 48 were a random ordering of equal numbers of the different types of display making up the list. The alphabet used consisted of 22 letters, the letters M, O, V and W having been omitted from the full alphabet. O was omitted because Ss occasionally called it 'zero' or

'nought' and the other three letters because their shapes in the 6 x 4 dot array alphabet used (see Figure 5) were judged by Ss to be particularly unnatural. The random letters in any display were always selected by sampling without replacement, so no letter ever appeared twice in a single display. SOA was always 40 msec.

S was instructed to press the push-button once to obtain the dim fixation spot in the centre of the screen. When he was ready and had the spot clearly in focus he pressed the button again to trigger the display. After the display he waited, still fixating in the centre. After an interval of two seconds a small figure made up of four dots was flashed briefly at the fixation position. This was the response cue and served as a signal to S that he should now write his response, in left to right order, in the window. This retention interval was used to make sure that the storage times of all letters reported were practically the same. The response cue was a horizontal line of three dots with a fourth dot a little below the line of the other three and either just to the left or just to the right of the line, randomly from trial to trial. S had to observe the position of the low dot and write his response accordingly on the left or on the right hand side of the window. This procedure simply guaranteed that S did not look down or start to write his response until the end of the retention interval.

Rather than requiring Ss to fixate on one position in the display and report a letter from a different position, the letters to be reported were defined in relation to the fixation position. Successive displays were presented at various positions on the screen so that

various letters were in line with the fixation position and so were to be reported. It was hoped that this procedure might reduce the importance of the identification of positions within the display. Another approach to solving the position identification problem was tried, but not adopted for the experiment. Various grids and markers surrounding the display positions were used in an attempt to define the display positions absolutely on the screen. But if vertical lines were placed between the letters the spacing within the display had to be changed and so metacontrast interactions were reduced, and if markers are placed just above and just below the display S still had to relate the letters to the markers. The extra confusion did not seem to be offset by any improvement in position identification, so no form of marking pattern was used in this experiment. (The marking pattern which was found to be the least confusing was used for the rather different task studied in Experiment XIV.)

S was told that only correct letters reported in their correct positions would be considered correct, and so if in doubt he should guess the identity of the letter at a particular position rather than make a position error by reporting a letter displayed in some other position.

Experiment Xa

In this part of the experiment the display conditions were arranged so that not only could S gain no benefit from fixating other than at the centre, but also that he needed to fixate correctly to be able to select the required letters to report. The displays were five random letters and the lists consisted of bl, blr, nb and nbr displays, mixed within

lists. The display parameters were arranged so that displays were aligned with either their second, or their third, or their fourth spatial position exactly at the fixation position. Successive displays were randomly in one of these three positions and within a list every type of display appeared equally often at each of the three positions. S was instructed to report the three adjacent letters closest to the fixation point, so if position 2 of a particular display was in the centre of the screen he would write down the letters in positions 1, 2 and 3 in that display. Similarly, if position 3 was at the fixation position he reported letters from positions 2, 3 and 4 and if position 4 was in the centre, letters from positions 3, 4 and 5.

Two Ss served, each for two sessions. Six lists were prepared and each S worked through two of these in his first session and three in his second. To introduce S to the fairly complicated display conditions, the first session started with a practice list of 14 sm displays. Then a second practice list of 14 displays of the same types as those in the experimental lists was given, at the start of each of the sessions. The letter presentation time was, as usual, 20 msec.

Experiment Xb

Performance in part Xa was too good to allow a useful analysis of item errors since the Ss made, on average, only 4 such errors per list, although a considerable number of position errors were made. So part Xb was identical except that the letter presentation time was reduced and each letter was intensified twice, once during each of two successive display cycles, rather than the usual six times. Presentation time was

about 6 msec rather than the usual 20 msec and the letters appeared dimmer, although single letters were still perfectly legible. Once again two Ss each served for two sessions.

Experiment Xc

Performance in part Xb was little worse than that in part Xa, so in part Xc a new difficulty was introduced. Displays were presented in one of three horizontal positions as before, but instead of being exactly in the centre vertically they appeared either just above or just below the fixation position. The vertical displacement of the centre of the letter immediately above or below the fixation position was equivalent to 0.9 deg. at the eye. Successive displays were randomly above or below the centre so S's best strategy should still have been to fixate exactly in the centre. Letter presentation time was 20 msec and two Ss each served for two sessions. Three practice lists, with increasingly complicated display conditions, were presented in the first session to introduce S to the complex task. Other details were as before.

Experiment Xd

This part was the same as part Xc, except that letter presentation time was reduced to 6 msec. Four Ss each served for two sessions.

Experiment Xe

The vertical displacement used in parts Xc and Xd certainly increased the number of item errors made, but it also increased the number of position errors. In an attempt to reduce the number of position errors,

part Xc used lists in which the two letters in each display which were not to be reported (those in positions 1 and 2, or 1 and 5, or 4 and 5) were replaced with rectangular checker-board dot patterns having the same size as the letters. Two Ss each served for two sessions, letter presentation time was 6 msec and other details were as for part Xc.

Experiment Xf

There were still many position errors, so in part Xf an attempt was made to decrease the confusion by separating the different display types into different lists. Six new lists were prepared, three consisting of an equal mixture of bl and blr displays only and three of nb and nbr displays only. Four Ss each served for two sessions and worked through one of each type of list in the first session and two of each in the second. Other details were as for part Xd.

Experiment Xg

Another approach was taken to the problem of reducing the number of position errors while still obtaining many item errors. Part Xg was identical to part Xd except that in the second session Ss reported all five letters in each display. This task was certainly difficult but Ss were prepared to tackle it in their second session. Four Ss served, but the results for one S were not analysed because she did not follow the instructions concerning the order of report.

Experiment Xh

In a further attempt to reduce position errors, displays were presented in only one horizontal position: with position 3 in line with the fixation position. Displays still appeared above or below fixation. Six lists were prepared and used in this part and all consisted of displays made up of five random letters. Two consisted of bl and blr displays, two of nb and nbr displays and two of sm displays. Six Ss served for two sessions and worked through one of each type of list in each session. In one session S reported only the letters in positions 2 and 4 and in the other only those in positions 1, 3 and 5. Letter presentation time was 6 msec.

Experiment Xi

It was clear that most interest would centre on the results for report from positions 2 and 4, in part Xh. So in part Xi report was always of the letters in positions 2 and 4. To reduce position errors the letters in positions 1, 3 and 5 of any particular display were the same, but different from both of the letters at positions 2 and 4. A typical display was, therefore, DXDAD and S should have reported XA. Other details were exactly as in part Xh. Again six Ss served for two sessions each.

RESULTS AND DISCUSSION

As the experiment progressed it became clear that the identification of the positions for report, together with the difficulty of seeing letters in some positions, was S's greatest difficulty. After some initial confusion during the practice lists all Ss managed well with the complications of the procedure: trigger, fixate, trigger, observe, wait, select response side and write response, and the uncertainty about exactly where the next display would appear on the screen. Ss made the usual comments about the appearance of the displays: there was apparent movement and the letters appeared to jump around, they would have guessed that there were only about three (or two, or four) letters in any display and in some displays three letters seemed to stand apart, with gaps between them. But it was difficult to select the letters for report because it was hard to associate letters with particular positions. Every S maintained he had fixated as instructed and that it was not too difficult to do so; some said that it helped, because it helped define the display positions.

So it appears that the fixation problem of the previous experiment was solved in this experiment, but that the difficulty in defining the display positions remained. Although Ss were encouraged to guess at letter identity rather than make position errors many Ss said that this was an impractical instruction. Many position errors were certainly made and once again it is not possible to know how many of these occurred because S was unsure of the identity of the letter at the position for report.

Part (no. Ss)		<u>bl, blr</u> 2,4		<u>bl, blr</u> 1,3,5		<u>nb,4</u> <u>nbr,2</u>		<u>nb,2</u> <u>nbr,4</u>		<u>nb,nbr</u> 1,3,5		<u>sm</u> 2,4
Xa	C	73		91		88		94		90		
(2)	I	3	1/10	3	0/10	5	1/8	1	0/1	4	3/16	-
	P	24	(315)	7	(396)	7	(160)	5	(160)	6	(400)	
Xb	C	83		91		94		89		93		
(2)	I	5	3/15	3	2/12	0	0/0	4	0/6	2	0/9	-
	P	12	(320)	6	(400)	6	(160)	7	(160)	5	(400)	
Xc	C	20		54		36		61		54		
(2)	I	17	11/53	23	8/91	20	9/31	16	4/25	21	10/84	-
	P	63	(313)	23	(388)=	45	(157)	23	(160)	25	(394)	
Xd	C	15		63		41		50		49		
(4)	I	17	21/109	11	9/86	9	6/28	6	1/20	10	16/81	-
	P	67	(626)	26	(784)	50	(309)	44	(312)	41	(783)	
Xe	C	60		71		73		87		85		
(2)	I	11	6/35	10	4/40	16	4/25	9	4/15	10	4/39	-
	P	29	(319)	19	(398)	11	(160)	4	(159)	5	(398)	
Xf	C	26		61		49		61		55		
(4)	I	15	13/112	11	11/101	9	6/33	6	1/22	6	2/61	-
	P	59	(755)	29	(949)	42	(381)	33	(383)	39	(952)	
Xg	C	27		68		40		46		56		
(3)	I	43	36/236	17	22/133	22	6/61	26	3/73	20	25/160	-
	P	30	(551)	15	(786)	38	(279)	28	(277)	24	(787)	
Xh	C	43		81		31		47		64		87
(6)	I	19	15/107	5	6/44	11	8/31	9	2/26	8	0/57	7 2/42
	P	38	(568)	13	(861)	58	(286)	44	(286)	28	(701)	6 (572)
Xi	C	64				37		54				77
(6)	I	17	25/189	-		15	14/86	17	11/96	-		15 28/176
	P	20	(1142)			48	(570)	29	(570)			8 (1152)

/.....

Table 10. Analysis of individual letter responses in Experiment X, for each part of the experiment and for different sets of display positions separately. In each cell the number in brackets is the total number of response letters and the three numbers in a column are percentages: top is percentage correct (C), middle is percentage of item errors (I) and bottom that of position errors (P). The fraction is the number of acoustic confusions over the total number of item errors. The number of Ss contributing data for each part of the experiment is shown at the left.

Scoring the responses

For the analysis, all responses written on the wrong side of the window, 1% of the total, were discarded. Individual letters in the remaining responses were then classified as correct if both letter identity and position were correct, or as an error. Errors were classified as position errors if the response letter had appeared at any other position in the display, or as item errors. Item errors were further classified as acoustic confusions and other item errors. The definition of an acoustic confusion was the same as that used in Experiment IX, except that the pairs C, G and M, N were not counted as acoustic confusions. Table 10 sets out the percentages of correct responses, item errors and position errors at the various different display positions in each part of the experiment. It shows the number of acoustic confusions as a fraction of the number of item errors and also the total number of response letters (the number in brackets) in each case. It is clear that the proportion of position errors was high in most cases. Examination of the raw data showed many instances of regular position errors e.g. in bl displays the letter in position 3 may have been given for that in position 4, or the letters in positions 1 and 3 interchanged.

General performance

Comparison of the pattern of percentages for bl and blr displays with that for nb and nbr displays showed no large differences. The two proportions of item errors were very similar in all parts of the experiment. The nb and nbr displays gave consistently higher proportions of correct responses in parts Xa to Xg, but lower proportions in parts

Xh and Xi. These differences were, of course, matched by changes in the proportion of position errors in the opposite direction. Parts Xh and Xi required report from positions 2 and 4 or 1, 3 and 5. These sets of positions were chosen with the appearance of bl and blr displays in mind and so, if these sets of positions were particularly hard to pick out in nb and nbr displays, it is reasonable that Ss made fewer correct responses and more position errors for nb and nbr displays in these cases.

Considering responses to positions 1, 3 and 5 only, performance was better with the bl and blr conditions and, in particular, more position errors were made in the nb and nbr conditions. The opposite was true for responses to positions 2 and 4. So it appeared that the difficulty was mainly concentrated in positions 2 and 4 in bl and blr displays, but more evenly spread in the nb and nbr displays. Once again suppressed letters were particularly difficult.

Acoustic confusions

Table 10 also shows the fraction of acoustic confusions in each cell. In many cases the numbers were small and no big differences were obvious from scanning the table; there were certainly not consistent differences comparable with that between 20% and 5% found with the second scoring method in Experiment IX. But there were big differences between the displaying conditions and the response procedures used in the two experiments and so it is reasonable that the proportions of acoustic confusions might be different in the two cases. For example, the introduction in the present experiment of the delay of two seconds before response may have increased the proportion of acoustic confusions

by increasing the partial memory loss, or have decreased it by increasing the total loss of items from memory and so increasing the number of random guesses.

In the third visual search experiment, Experiment VIII, letters presented third in nb and nbr displays, i.e. those in positions nb,4 and nbr,2, gave results similar to those for letters in positions 2 and 4 of bl and blr displays (see Figure 13). Inspection of the results in the present experiment suggested that here, too, they gave results similar to those for suppressed letters. Accordingly, in the analysis of proportions of acoustic confusions, the results for nb,4 and nbr,2 were grouped, but kept separate from those for nb,2 and nbr,4. Comparisons of proportions of acoustic confusions between conditions were made within Ss and for as many parts of the experiment as gave relevant results. Table 11 shows the comparisons made.

The data used in any particular comparison consisted of 25 or 31 (the total number of Ss in the parts of the experiment concerned) pairs of fractions, one for each S. A test for a difference between members of the pairs might have weighted each pair equally or might have taken into account the different numbers of item errors on which the fractions were based. A Wilcoxon test, which weights each pair equally, was applied in the usual way to the differences between the fractions forming the pairs. It had the advantage that every S was considered equally important, but the disadvantage that small numbers, e.g. 1/5 (20%), were weighted equally with larger numbers, e.g. 7/35 (also 20%). So the Cochran test used for Experiment IX was also applied here. It had the advantage that very small numbers made only a small

Comparison of	with	Parts in comparison	Percentages of acoustic confusions		Significance levels (two-tail tests)	
					Cochran	Wilcoxon
(1)	<u>bl,blr</u> ;2,4 <u>bl,blr</u> ;1,3,5	Xa-Xh	15.1	12.0	<0.05*	<0.05*
(2)	" " <u>nb,nbr</u> ;1,3,5	Xa-Xh	15.1	11.8	<0.025	<0.005
(3)	" " <u>nb</u> ;4; <u>nbr</u> ,2	Xa-Xi	15.1	17.8	ns	ns
(4)	" " <u>nb</u> ,2; <u>nbr</u> ,4	Xa-Xi	15.1	10.9	<0.05	<0.025
(5)	<u>nb</u> ,4; <u>nbr</u> ,2 " "	Xa-Xi	17.8	10.9	<0.05*	<0.01
(6)	" " <u>nb,nbr</u> ;1,3,5	Xa-Xh	17.8	11.8	<0.01	<0.01
(7)	<u>nb</u> ,2; <u>nbr</u> ,4 " "	Xa-Xh	10.9	11.8	ns	ns
(8)	$\left\{ \begin{array}{l} \text{bl,blr;2,4} \\ \text{nb,4;nbr,2} \end{array} \right\} \left\{ \begin{array}{l} \text{bl,blr;1,3,5} \\ \text{nb,nbr;1,3,5} \\ \text{nb,2;nbr,4} \end{array} \right\}$	Xa-Xh	15.8	11.7	<0.001	<0.001
(9)	" " <u>sm</u> ,2,4	Xh	16.7	4.8	<0.05*	<0.05
(10)	" " "	Xi	15.3	15.9	ns	ns
(11)	" " "	Xh, Xi	15.7	13.7	ns	<0.05*

Table 11: Comparisons of proportions for Experiment X of acoustic confusions in different display conditions. The second column shows which parts of the experiment contributed data to the comparison and the next column gives the percentages of item errors which were acoustic confusions in the two conditions being compared. The last column shows probability values for two tests for a difference when the data are matched pairs. For the Cochran test see Maxwell (1961).

* for one-tail test only.

contribution, but this had the effect of giving greater weight to the Ss who made most errors. Examination of the data for the individual Ss suggested that the few Ss who made a very large number of errors showed smaller differences in the proportion of acoustic confusions between conditions than did other Ss. Such a trend is consistent with the difference in significance levels shown by the two tests for the same comparisons (see Table 11). Also, it would suggest that the percentages shown in Table 11 under-estimate the differences, since these percentages were calculated from the numbers of errors pooled over Ss rather than being the means of the percentages for individual Ss.

Table 11 shows that there was a difference between the proportion of item errors which were acoustic confusions for suppressed letters and that for other letters. The difference was small, but consistent and significant and in the direction expected. The results concurred with those of Experiment VIII in suggesting that letters in positions nb,4 and nbr,2 behave like suppressed letters. Comparison (3) in Table 11 showed that their acoustic confusion proportion did not differ from that for suppressed letters and comparison (5) showed that it was greater than that for nb,2 and nbr,4 letters. When the nb,4 and nbr,2 results were grouped with those for the suppressed letters and compared with all other results (comparison (3)) the difference between the acoustic confusion proportions was significant at the 0.001 level. It remains puzzling why the nb,4 and nbr,2 positions should have behaved in this way, considering that descriptions of nb and nbr displays never mention missing letters or blank spaces at these positions. Table 10

shows that the proportion of correct responses at the nb,4 and nbr,2 positions was nearly always lower than that for other nb and nbr positions, although not as low as that for positions 2 or 4 of bl and blr displays: so in this way also their results somewhat resembled those for suppressed letters.

Parts Xh and Xi allowed a comparison with results for letters in positions 2 and 4 of sm displays. In part Xh the proportion of acoustic confusions for these letters was very small (see Tables 10 and 11), but in part Xi it was the same as that for suppressed letters. Perhaps this result in just one part of the experiment should not be given very much weight.

Migration errors

One of the further analyses carried out, but not fully reported here, was the classification of position errors into those for which the correct letter was given elsewhere in the same response and those for which it was not. If the correct letter was given elsewhere the error was called a migration error. So, for example, a simple transposition was scored as two migration errors and, if ABCDE was presented and DACKXE given as the full response, a migration error was scored for position 1 since the D was a position error and the correct letter for that position, A, occurred elsewhere in the response. On this definition 20% of the position errors at positions 2 and 4 of bl and blr displays were migration errors, but the figure for nb,2 and nbr,4 was 47%. So suppressed letters seldom appeared in the response in the wrong position, while migration errors from nb,2 and nbr,4 were fairly common. Once

again the figure, 32%, for nb,4 and nbr,2 was below that for the nb,2 and nbr,4 positions although not as low as that for positions 2 and 4 of bl and blr displays.

The proportion of position errors which were migration errors for positions 1, 3 and 5 of bl and blr displays was 65% and much of the migration was certainly to positions 2 and 4. The figure for positions 1, 3 and 5 of nb and nbr displays was 42% and there was no such single marked migration pattern. Recalling that the overall proportion of position errors was higher for nb and nbr displays than for bl and blr displays if suppressed positions were ignored, the best general conclusion is that seeing suppressed letters was the main difficulty in the bl and blr displays, but that in nb and nbr displays more letters could be identified but it was more difficult to assign them correctly to their positions. A qualification to the conclusion is that letters in position nb,4 and nbr,2 behaved rather like suppressed letters.

Summary

In summary, Experiment X supported the two main findings of Experiment IX. First, it is a very difficult and confusing task just to 'write down the letters in the display'. It is also difficult to find appropriate cues or display conditions which help S with the position identification part of the problem. Second, a greater proportion of item errors made to suppressed letters are acoustic confusions than is the case for other letters. This experiment gave no results requiring modification of the interpretation given during the discussion of

Experiment IX: suppressed letters are sometimes named and then visual information about them is lost. Letters in positions nb,4 and nbr,2, which gave results resembling those of suppressed letters in Experiment VIII, showed the same acoustic confusion proportion as suppressed letters and gave other results somewhat resembling those for suppressed letters. Finally, overall performance with b1 and blr displays was about equal to that with nb and nbr displays. But while the main difficulty with b1 and blr displays was seeing suppressed letters, with nb and nbr displays it was relating the letters in the display to the correct display positions.

CHAPTER 8

Comparisons of Letters in Metacontrast

Experiment XI: Ss make same or different judgements about pairs of letters. Visual and acoustic confusibility of the letters forming pairs are manipulated and RTs and error rates indicate that visual matching is comparatively less important if one of the letters in the pair is suppressed.

Experiment XII: The task is made more complicated, but any relation between acoustic confusibility and metacontrast fails to reach significance.

Experiment XIII: Ss make same or different judgements between entire displays.

8.1 Same or Different Judgements

The experiments reported in Chapter 7 found some evidence that suppressed letters can sometimes be named even though visual information about them is quickly lost. But the letter report tasks used required Ss to identify the positions at which letters were displayed and this was found to be difficult. In this chapter some experiments taking a different approach to letter naming are described. Their aim was to avoid the position identification problem and to seek confirming evidence that suppressed letters can be coded and stored as names. They required Ss to match a cue letter with a test letter presented in a metacontrast

display and to press one of two keys as quickly as possible to signal whether the two letters were the same or were different. When the two letter were different they were either acoustically confusable or visually ~~w~~confusable, and so any differential effects of these two types of confusibility on RTs or error rates would indicate that S was relying relatively more on name or shape coding. The line of thinking underlying these experiments is similar to that underlying a large amount of recent work on the recognition, coding and storage of simple visual stimuli. So these experiments provide an example of the use of the strategy suggested in Chapter 2 that visual masking studies might make good use of the results and techniques of work investigating human information processing. Before describing the experiments some of the relevant work in this field will be mentioned.

Hayes, Robinson and Brown (1961) required Ss to judge whether two simultaneously presented forms were the same and found that they judged two reversed letters to be the same just as quickly as two letters in the correct orientation. So the recognition or naming of the forms as letters did not appear to be important and the comparison was presumably made at an earlier processing stage. Hochberg (1966) used meaningful and nonsense words in a similar matching task and found that familiarity of the material was only important if the task required S to memorise or transform one of the stimuli before he could match it with the other, such as when the words were separated in space or time, or were in different type-faces. Posner and Mitchell (1967) measured RTs for same and different judgements made to pairs of

simultaneously presented letters. Three criteria for sameness were used: physical identity (AA), name identity (Aa) and vowel-consonant class identity (AE), and matching times under the three criteria were found to increase in this order. Posner and Keele (1967) studied physical identity and name identity matches of two successively presented letters. If the letters were presented simultaneously physical identity matches were some 90 msec faster than name identity matches, but the difference decreased as the time between the two presentations increased and had nearly disappeared when one letter was presented 1.5 sec after the other.

The assumption underlying the interpretation of these experiments is that any additional transformations or manipulations which must be applied to characters in order to perform a task will lengthen RTs and conversely, if RTs in two similar conditions are different, then in the situation yielding the longer RT some extra operation must be required before the response. The interpretation is that visual matching of letters or simple shapes is fast and efficient and may be carried out without naming the stimuli. Name matching and class matching take longer because extra operations must be applied to the input before the required comparison may be made. With successive presentation visual matching can still occur and is more efficient than name matching if the interval between the two presentations is short, but it becomes less efficient as the interval increases because the visual information about the first letter decays with time. This visual storage is not just the icon because the time course of decay is not affected by variation in physical parameters, such as brightness, nor by introduction of visual

noise during the inter-stimulus interval (Posner, Boies, Eichelman and Taylor, 1969). But it is affected by an information processing task, such as adding 3 to a digit presented auditorily and saying the result, so it seems to require attention or rehearsal of some kind (Boies, 1968; Posner and Konick, 1966). There is also evidence that S may maintain the visual information more efficiently and for longer if it is especially important or helpful to do so.

Further experiments (Posner et al., 1969) asked whether S can generate some form of visual representation of a letter presented auditorily, so that a visual match with a second letter, presented visually, may be made. The findings suggest that S can do this, provided that he has at least 0.75 sec in which to generate the visual code. Matches are then more efficient than name matches, although they are not as efficient as physical matches for simultaneously presented letters.

Posner (1970) gave a review and a theoretical discussion of this whole field of work.

In the experiments mentioned so far, two different criteria for sameness were used so that visual and name matching could be distinguished. Manipulation of the visual and acoustic confusibility between the letters in a pair offers another method for discovering whether shape or name coding is relatively more important in a particular task. Dainoff and Haber (1970) used a same-or-different task with pairs of simultaneously presented letters as stimuli. Acoustic confusibility increased RTs for

name matches but not for physical matches. The authors discussed whether the name and visual analyses proceeded in series or in parallel and did not make a firm choice, although they preferred the view that physical, visual analysis occurred first and was followed by acoustic, name analysis. Dainoff (1970) found that with successive presentation the effect of acoustic confusibility increased as the interval increased. He concluded that the likelihood of auditory encoding increased over time and that since maintenance of a visual code decreased with time (as Posner and Keele (1967) had also found) the two forms of coding could be handled quite separately. Posner and Taylor (1969) used a matching task between a three-letter array, followed by a visual noise-field, and a single probe letter presented after the noise-field. They manipulated the visual and acoustic confusibility of the three letters in the array and excluded any effects of confusibility between these letters and the probe letter by considering only trials in which the correct response was 'same'. Their results showed that in their conditions confusibility affected the initial encoding stage rather than the matching stage and that visual confusibility reduced the efficiency of physical identity matches without affecting name matches, so the visual and name codes were stored separately and need not have been interrogated serially, although they may possibly have been formed serially. Cohen (1969) required Ss to match two successively presented trigrams of lower case letters. The two trigrams were either the same, or they differed at just one position. In 'different' trials the two different letters were not confusable (t,q), or they were visually

confusable (p,q), or they were acoustically confusable (t,p), or they were both visually and acoustically confusable (b,d). RTs and error rates for the first three conditions were the same, but performance was slower and less accurate in the single case when the different letters were both visually and acoustically confusable. This result suggested that in these conditions S was making a visual and a name comparison in parallel and that either could lead to a decision and response, so that only if both comparisons were disrupted would a drop in efficiency be seen. In this experiment confusibility was between the two successively presented letters to be matched rather than within the initial display, so it must have had its effect during matching rather than during the initial encoding.

In summary, the study of simple matching tasks allows the separation and study of a physical, visual comparison process, an acoustic, name comparison process and other classificatory processes as well. RT and error rates are the performance measures used. The different processes may be separated by using several criteria for sameness, or by manipulating various types of confusibility between the stimuli to be compared.

In our study of metacontrast in displays of letters we would like to know in what form a suppressed letter is represented in memory, if it is represented in memory at all. We could compare matches between letters in the same case and those in different cases, or we could manipulate the visual and acoustic confusibility of letter pairs. It was not possible to obtain enough satisfactory lower case letters with the display equipment available, so the second method was used in the three experiments described in this chapter.

8.2 Comparisons of Letters in Metacontrast

Experiment XI : Comparisons of letters presented among visual noise patterns.

In each trial in this experiment S made a keypress response to signal whether he judged a cue letter and a test letter to be the same or different. The test letter was presented in a display with four nonsense forms and the cue letter was presented by itself. Successive presentation was used and in some lists the cue letter came first; in others it came second.

METHOD

Four types of list were used. In two the cue letter always preceded the display and in two it followed it, and in one of each of these types the interval between cue letter and display was short while in the other it was long. The four conditions were, therefore, called PRE-SHORT, PRE-LONG, POST-SHORT and POST-LONG, where PRE and POST refer to the pre- and post-cueing conditions i.e. those in which the cue letter came before and after the display, respectively. Pilot work showed that the shortest practical cueing interval (CI), the interval between cue letter offset and display onset, or display offset and cue letter onset, was 280 msec. If a shorter CI was used S was likely to confuse the cue letter with the display and the aim was to make the cue letter virtually perfectly visible. A long CI, of 1.73 sec., was chosen to allow sufficient time for a considerable loss of visual information to occur. So the CI was 0.28 sec in the SHORT conditions and 1.73 sec. in the LONG conditions. All trials in a list had the same CI and the same cueing order.

A pairs

BT	BP	BE	BG	CB	CE	CT	CP	DT	DP
DE	EC	ED	ET	EG	GB	GE	LN	LS	LX
PB	PT	TB	TP	FX	FS	FL	SF	SX	XS
IY	YI	QU	UQ	JA	AJ	JK	KJ	AK	KA

V pairs

AR	BR	BS	CU	DQ	EF	FE	FP	FT	GQ
GL	HI	HN	HU	IT	IJ	JT	JI	KX	KP
KN	LU	LG	NH	NR	PR	PA	QD	QP	RP
RB	SP	SB	TI	TJ	UJ	XH	YK	YX	ZX

Table 12: The pairs of letters used to form A trials (A pairs) and V trials (V pairs). The two letters in an A pair were considered to be acoustically confusable but not highly visually confusable. The two letters in a V pair were considered not to be acoustically confusable and, on average, more visually confusable than letters within A pairs. In every case the first letter shown became the test letter in the trial and the second became the cue letter.

In every trial the test letter and four nonsense forms (Figure 5 shows the nonsense forms used) made up the display and this always appeared in the middle of the screen. The test letter appeared equally frequently at each of four display positions (it never appeared in position 3, the central position). Each character in the display was presented for 20 msec, SOA was 40 msec and the display orders used were bl, blr, nb and nbr. The cue letter was presented for 150 msec by itself in the centre of the screen. In any trial the test letter and cue letter were the same (an I pair) or were different and acoustically confusable (an A pair) or were different and not acoustically confusable (a V pair). Eight experimental lists, two in each of the four main conditions, were prepared. Every list started with two warm-up trials, then consisted of a random ordering of 64 I trials (cue letter and test letter the same), 32 A trials (cue and test letters were an A pair), and 32 V trials (cue and test letters were a V pair). In each category the 16 possible combinations of the display orders (bl, blr, nb and nbr) and test letter position in the display occurred equally frequently i.e. twice for A and V trials and four times for I trials.

The letters M, O, V and W were excluded and so an alphabet of 22 letters was used. 40 pairs of acoustically confusable letters were chosen to provide a pool for the A trials and 40 pairs of letters which were not acoustically confusable were chosen to provide a pool for the V trials. The pairs chosen are shown in Table 12. The selection of pairs was subjective but took into consideration the analyses of acoustic confusibility given by Conrad (1964) and Wickelgren (1965, 1966), the

dot patterns used to form the letters (see Figure 5) and the results of Experiment IX. Pairs of letters which were acoustically confusable and also very similar visually were omitted entirely, e.g. BD, CG. It can hardly be claimed that within every V pair the letters were very similar visually, but it is reasonable to assume that letters in V pairs were, on average, more visually confusable than those in A pairs. Taking, for example, the number of dots two letters have in common as an objective measure of visual confusibility, the average for A pairs was 6.8 dots while that for V pairs was 8.3 dots.

An experimental list was made up by selecting 32 pairs randomly from the pool of A pairs and 32 pairs randomly from the pool of V pairs. 64 I pairs were selected so that any one letter appeared about equally often in I trials and in A or V trials, even though the 22 letters did not appear equally often in the experiment. A display order and a test letter position were assigned randomly to each trial with the constraint mentioned above that each of the 16 combinations of these variables occurred equally frequently within types of letter pair.

Four practice lists, one for each of the main conditions, were made up in a similar fashion and consisted of just 20 trials. Two further practice lists were prepared, one in the PRE-SHORT condition and one in the POST-SHORT condition. These lists consisted of 22 trials and used every letter being used in the experiment as the cue letter in just one trial. These lists were used to check that S could recognise the 22 letter shapes and that the cue letters were not being confused with the display at the short CI.

Ten Ss served for two sessions each in the experiment. One session was devoted to pre-cued trials and the other to post-cued trials. In each session S worked through four experimental lists. The order of sessions, order of use of CI values and order of use of the eight lists were all counterbalanced over Ss. In lists using the short CI the S-S interval was held constant at 2.0 sec, and in the long CI lists it was held constant at 3.5 sec. A fixation spot was presented in the centre of the screen at the start of every list and S was instructed to fixate on the spot and to keep looking in that same position throughout the list as that was where the cue letter always appeared and where the centre of the display fell. S was also instructed to work as quickly as possible, while still making few errors. If in doubt he was to guess.

The first practice list used in each session was the appropriate one of the two lists consisting of 22 trials. For this list S did not give any keypress responses but simply read the cue letter aloud as E triggered presentation of the trials one by one.

The assignment of the two responses, same and different, to the two keys was kept constant for any one S, but was varied over Ss so that the dominant hand was used for the same response by half the Ss.

RESULTS AND DISCUSSION

The first two trials in each list were excluded from the analysis. RTs were measured from the first time at which sufficient information was available for a correct response to be made. So in post-cued trials RT was measured from the onset of the cue letter, while in pre-cued trials RT was measured from the onset of the test letter, whenever during the display of nonsense forms it was presented. RTs less than 150 msec or greater than 1500 msec, or more than three standard deviations from the mean of the remaining RTs of the same type (meaning A or V or I) in the same list were discarded. 1.7% of all RTs were excluded in these ways. The mean RT and the percentage of error were then calculated for each condition for each S.

Inspection of the data

The first expected result was that in the POST condition A trials would be difficult if the test letter was suppressed. This prediction followed from the finding of Chapter 7 that a suppressed letter might be stored only as a name; if so, acoustic confusibility should be disrupting. Inspection of the results, averaged over Ss, showed no clear evidence confirming this prediction. The hope was that given such a very specific prediction confirmation might be made simply by applying one or two t-tests, but both the RT and the error results showed complicated patterns of values and any effect was too small to emerge on simple inspection.

Another particular question asked concerned the nature of the matches made to suppressed test letters in the PRE condition. Could S make a simple, fast shape match, or did he have to name the test letter and only then match it with the stored cue letter? Once again inspection did not suffice.

One observation did emerge from the initial inspection of the data and this was simply that long RTs and high error rates seemed to be associated quite closely, so it seemed reasonable to accept either as evidence of difficulty or inefficient processing.

Analyses of variance

Three series of 5-way analyses of variance were applied to the results. No attempt will be made to give an exhaustive account of these because the complexity of the display conditions means that a full description of the analyses would be extremely complicated and; because many of the effects found were not of interest anyway. Instead a description will be given of just what analyses were carried out, then the main findings will be sketched and finally the results relevant to our investigation of metacontrast will be discussed in detail.

All the analyses were carried out separately for percentages of error, with an arcsine transformation, and for RTs. In the first series the factors in each analysis were: A (LONG/SHORT); B(Ss); C(I/D); D(bl,blr/nb,nbr); E(1,ii/iii,iv). The lower case Roman numbers refer to the temporal order of presentation, so that an 'ii' trial is one in which the test letter was presented second in time,

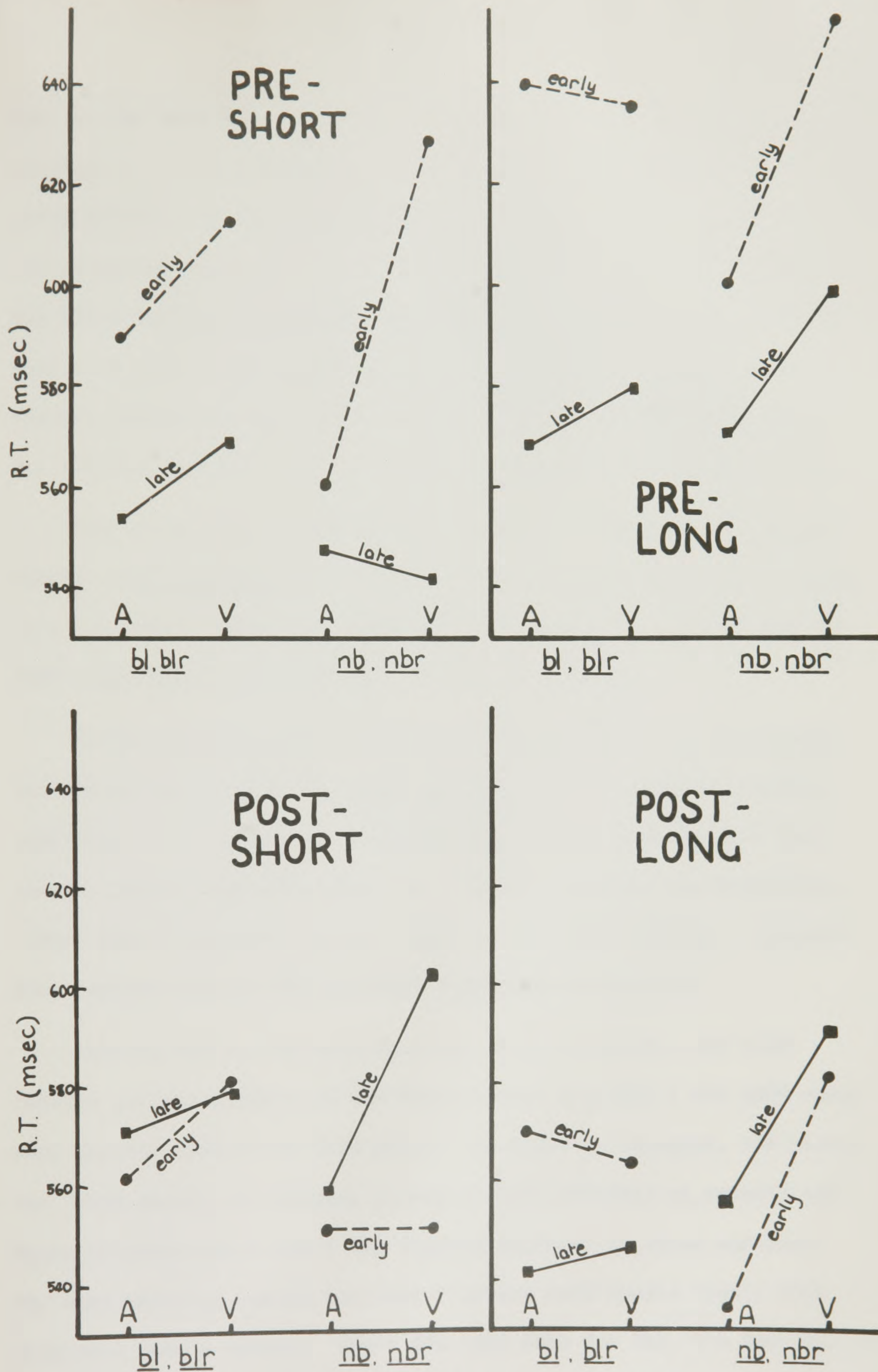


Figure 16. Experiment XI. All the correct, D R.T.s.

early: test letter in position i or ii

late: " " " " iii or iv

e.g. it may have been in spatial position 2 of a bl display, or in position 3 of an nb display. Factor E therefore refers to the classification of trials according to whether the test letter was presented early (i or ii) or later (iii or iv) in the display. The third factor in the analyses was I/D, referring to the classification of trials into same and different trials; D trials were not further classified into A and V trials. Analyses were carried out for the PRE and POST conditions separately and for the two together.

The factors in the second series were: A (LONG/SHORT); B(Ss); C(A/V); D(bl,blr/nb,nbr); E(i,ii/iii,iv), so that only A and V trials were included. Once again analyses were carried out for the PRE and POST conditions separately and for the two together.

In the third series the factors were the same as in the second but the display orders (bl, blr, nb, nbr) and the temporal display positions (i, ii, iii, iv) were each classified into the full four levels, rather than into only two. So each analysis was $2 \times 10 \times 2 \times 4 \times 4$, rather than $2 \times 10 \times 2 \times 2 \times 2$ as were those in the second series. Analyses were carried out for PRE and POST conditions separately.

Turning now to the main findings of the analyses, the only notable general finding of the first series was that I RTs (504 msec) were shorter than D RTs (578 msec). As would be expected, the second and third series of analyses showed similar patterns of results and Figure 16 shows the A and V RTs results relevant to those analyses. The most striking result was that V trials were consistently more difficult than A trials. The V RTs (602 msec for PRE, 574 msec for POST)

	<u>bl,blr</u>	<u>nb,nbr</u>
1,ii	581	570
iii,iv	539	542

Table 13A: Mean RTs in msec, for I and D trials together, relevant to the DxE interaction in the PRE, RT analysis in the first series in Experiment XI.

	A			V		
	<u>bl,blr</u>	<u>nb,nbr</u>	mean	<u>bl,blr</u>	<u>nb,nbr</u>	mean
1,ii	615	580	/ <u>598</u>	624	640	/ <u>632</u>
iii,iv	562	559	/ <u>560</u>	575	570	/ <u>573</u>
mean	(539)	(570)		(600)	(605)	

Table 13b: Mean PRE RTs in msec for the CxDxE interaction. The four underlined values show the CxE interaction and the four values in brackets the CxD interaction for Experiment XI.

	<u>bl,blr</u>		<u>nb,nbr</u>	
	A	V	A	V
LONG	556	555	545	586
SHORT	<u>567</u>	<u>579</u>	<u>555</u>	<u>576</u>
mean	(562)	(567)	(550)	(581)

Table 13c: Mean POST RTs in msec for the AxCxD interaction. The four bracketed values show the CxD interaction for Experiment XI.

	<u>bl,blr</u>			<u>nb,nbr</u>		
	A	V	mean	A	V	mean
LONG	4.8	5.8	/ <u>5.3</u>	3.8	12.3	/ <u>8.1</u>
SHORT	8.4	13.8	/ <u>11.1</u>	7.4	11.6	/ <u>9.5</u>

Table 13d: POST error percentages for the AxCxD interaction. The four underlined values show the AxD interaction for Experiment XI.

were longer than the A RTs (579 msec for PRE, 556 msec for POST) and the V error rates (11.7% for PRE, 10.8% for POST) were greater than those for A trials (6.4% for PRE, 6.1% for POST). In the PRE condition RTs were measured from the onset of the test letter. In the visual search experiments described in Chapter 6 the pattern of RTs often suggested that S waited till the end of the display before initiating a response; if there was any such tendency in the PRE lists of the present experiment it would be shown by the measured RTs for i and ii trials being longer than those for iii and iv trials. If the tendency was complete this difference would have been 80 msec. It was observed to be 20 msec for I trials and 54 msec for D trials, so there was some tendency to delay response selection until the end of the display although 'same' responses were less affected by it. Overall difficulty of i and ii trials and the shorter warning in these than in iii and iv trials may also have contributed. Finally, in the POST condition, performance was slightly worse when the test letter appeared in an inner position (spatial position 2 or 4) than when it was in an outer position (position 1 or 5).

Findings relevant to metacontrast

Turning to the results of interest in our study of metacontrast, we find only one in the first series of analyses. The DxE interaction was significant ($p < 0.005$) in the PRE, RT analysis and Table 13a shows the relevant average RTs. To recapitulate, the symbols used in Table 13a mean that the average RT for all PRE trials with the bl or the blr display order, and with the test letter in the (temporal)

position i or ii, was 581 msec. Since the first two characters in these display orders were suppressed this simply means that the mean RT for trials with suppressed test letters was 581 msec. The interaction suggested that suppressed letters were in general the most difficult. The effect was specific to PRE lists and there was no interaction with I/D or SHORT/LONG.

The second and third series of analyses showed another effect in the PRE, RT results. The CxD, CxE and CxDxE interactions were all significant ($p < 0.05$); the relevant means are shown in Table 13b. The four underlined values are relevant to the CxE interaction and suggest that visual confusibility was particularly disrupting when the test letter appeared early (in positions i or ii), whatever the display order. The figures for the CxDxE interaction suggest that this tendency was stronger for nb and nbr trials than for bl and blr trials.

Consideration of Tables 13a and 13b and the top half of Figure 16 suggests that the largest effect was the big disruption produced by visual confusibility for early test letters in nb and nbr displays. *The RT results suggest that* suppressed test letters were in general the most difficult and acoustic confusibility was relatively more disrupting than visual confusibility for them, by comparison with early nb and nbr test letters. But without a no confusibility condition it was not possible to separate confidently the effects of the two types of confusibility. The best conclusion is probably that visual comparisons were the most important, that visual information about suppressed letters was degraded or removed and so visual comparisons were comparatively less important in that case, and that acoustic confusibility did not appear to disrupt greatly whatever name comparisons did occur.

The one interesting effect in the results for the POST condition appeared both in the RT and the error analyses of the second and third series. In the POST, RT analysis the AxCx $\bar{D}$ and the Cx $\bar{D}$ interactions were significant ($p < 0.05$) and the relevant values are shown in Table 13c. The Cx $\bar{D}$ interaction (see the four bracketed values) shows that the A and V conditions gave very similar RTs for bl and blr while the nb and nbr displays showed the usual difference, so for bl and blr displays acoustic confusibility was particularly difficult or visual confusibility was particularly easy or both. The values shown for the AxCx $\bar{D}$ interaction suggest that visual confusibility was particularly disrupting for nb and nbr displays and a little less disrupting than expected for bl and blr displays, but only at the long cueing interval.

Turning to the POST error analysis, the AxCx $\bar{D}$ and the Ax $\bar{D}$ interactions reached significance ($p < 0.05$) and the relevant values are shown in Table 13d. The Ax $\bar{D}$ interaction (see the four underlined values) shows that the error rates at the two CIs (LONG and SHORT) were similar for nb and nbr displays but much lower for LONG than SHORT for bl and blr displays. The AxCx $\bar{D}$ interaction suggests that this was mainly caused by either an unexpectedly low error rate (5.8%) in the LONG, V, bl and blr condition, or an unexpectedly high error rate (12.3%) in the LONG, V, nb and nbr condition, or that both these tendencies contributed. A comparison of Tables 13c and 13d shows that the RT and the error results show similar patterns. Both suggest that visual confusibility at the long CI are disrupting for nb and nbr displays but, in particular, did not interfere with matching when the test letter had appeared in a bl or blr display.

General discussion

The first implication of this last result (and the earlier finding that visual confusibility was disrupting in general in the experiment) is that some form of visual code, sufficiently strong to interfere with a match with a letter of similar shape, remained even 1.73 sec after displayoffset. This may have been an icon, since the letters appeared brightly on the screen, there was no following noise-field and the illumination during the CI was fairly dim, but even so, 1.73 sec is longer than most estimates of the duration of the icon (see Chapter 2). It is more likely to have been a visual code of the form investigated by Posner and his colleagues (see Section 8.1) since, although 1.73 sec is also near the upper limit of the estimates of the duration of this type of code, it is perhaps possible that the code was sustained by an icon for the first two or three hundred milliseconds of its life and it is also likely that S rehearsed or regenerated the code and thus prolonged its useful life. A second implication of these results is that this visual code was absent or weak at the end of the long CI when the test letter had appeared in a bl or blr display. By itself this is a reasonable result, that visual information was removed when the test letter appeared in a metacontrast display, even though the 4-way interaction necessary to limit the effect to suppressed letters was not significant. But it remains to be explained why visual confusibility was much more disrupting at the short than at the long CI for bl and blr trials. It is not sufficient to observe that the long and the short CIs were in separate lists and to postulate that there was a strategy difference, for the bl, blr, nb and nbr orders and the A and V conditions were all

mixed within lists, and so it is very difficult to find plausible strategies which might have given the full set of results. One interpretation assumes that the icon of a suppressed test letter was destroyed soon after presentation but that a reasonable visual code of the test letter was available at first. This was sufficiently strong to disrupt a match with a visually similar cue letter 0.23 sec later, but did not survive for sufficiently long to give interference at the long CI. Because so much interference was observed at the short CI it is not sufficient to assume that the initial visual code was weak and so decayed fast, unless a ceiling effect is invoked. It appears necessary to assume that the initially strong visual code decayed quickly, perhaps because S did not have a normal icon of the letter at first and so, for some reason, he could not rehearse the visual code. The best conclusion at this point is probably that metacontrast disrupts the storage of visual information about a suppressed letter but that further deductions would demand too much from the observed results.

One important problem remains: how did S make such accurate matches at the long CI with suppressed letters? A trials were not particularly difficult and yet we have also argued that little visual information remained 1.73 sec after display presentation. There seem to be three possibilities. First, all matching might have been entirely visual and the removal of some visual information when the test letter was suppressed actually improved performance on the V trials by decreasing the impact of visual similarity between the letters being matched. This appears implausible, particularly considering the comments of Ss mentioned below, that they named letters frequently, and the results

discussed in Section 8.1 that the tendency to use a name increases with delay and is strong after 1.73 sec. Another possibility is that visual and acoustic comparisons proceeded in parallel, that the visual comparison predominated so that visual confusibility was disrupting, except in the LONG, V, bl and blr condition in which a name match terminated first, and that visual matches terminated first in A trials. Finally, name matching may have occurred frequently but without acoustic confusibility producing very much disruption. We cannot choose between these last two possibilities, although the work mentioned in Section 8.1 suggests that the last one is unlikely.

No further findings of the analyses remain to be described, but the comments of Ss should be mentioned. In spontaneous descriptions of the task S described many strategies used including naming and sub-vocal rehearsal to retain a letter during the long CI, naming of several possibilities if there was doubt, the retaining of shapes of letter fragments if that was all that was seen and the deliberate construction of an 'image' to achieve a fast visual match. Clearly such strategies, if adopted consistently, could markedly change the observed pattern of RTs and error rates and it would be interesting to know which strategies Ss would prefer for different display conditions, but conditions were mixed within lists in this experiment and so no account of strategy differences could be taken. It is interesting that only one S on one occasions made any comment about the necessity to search through the display and find the letter by rejecting nonsense patterns. This S commented that the nonsense form used resembled a B. But, on the whole, Ss described only the matching task as if the location task was not

noticed. Pilot work had also suggested that locating the test letter in nonsense forms was a fairly easy task, even when it was suppressed, but this does not alter the fact that preliminary analysis to locate the test letter was required before matching could commence. It was not possible to separate any effects of the location task and the matching task in the observed performance.

No mention has yet been made of test letters in the nb,4 and nbr,2 positions; letters in these positions gave results resembling those of suppressed letters in visual search and letter identification experiments described earlier. It was hoped that their results could be considered separately and used in appropriate t-tests, but the effects were not sufficiently clear-cut. Following the analyses of variance the results contributing to the four parts of Table 13 were classified further to separate the values for these two positions from those for other nb and nbr positions. Comparisons of values for trials with test letters in positions nb,4 or nbr,2 with those for trials having suppressed test letters showed only ambiguous patterns. Letters in these positions seemed, if anything, not to resemble suppressed letters in their effects, but little confidence can be placed in this observation.

The general strategy of arguing from significant interactions in analyses of variance can be criticised on at least two grounds. First, any particular observed interaction may be interpreted in several ways; the argument must rest on the judged greatest plausibility of the interpretations given. Second, many related analyses were carried out, there were many effects which may have reached significance, but no useful

estimate of the probability of making Type I errors could be made. Even though the significance levels were only moderate (0.05), the effects discussed probably were real, however, since two or more observed interactions contributed to each, except in the first case (shown in Table 13a), for which $p < 0.005$. The effect shown in Tables 13c and 13d is particularly convincing because the RT and error patterns agreed.

Summary

This experiment showed that the task used was mainly a visual task. It relied on S being able to locate the test letter in the display of nonsense forms and the results and Ss' comments showed that this was not very difficult, even when the test letter was suppressed. Performance was, in general, very good, the overall error rate being just less than 10%. In the discussion of sequential blanking given in Section 3.5 it appeared that similarity of form between blanking and blanked characters, and difficulty of organisation of the whole display or labelling of the blanked characters were both involved in the phenomenon. It was not possible to assess the relative contributions of the two. But in the present experiment the test letter was always different in shape from the nonsense forms and it was also easy to distinguish or label since all other characters were identical nonsense forms. So it is perhaps not surprising that suppression in such displays was not very marked and this may explain why the effects related to metacontrast obtained in the experiment were small. These results were that, in the pre-cueing condition, suppressed test letters were the most difficult, and although visual confusibility was particularly disruptive when the

test letter appeared early in the display (at positions 1 and 11), visual confusibility was relatively less important for suppressed test letters. In the post-cueing condition both the RT and error results suggested that metacontrast interfered with the storage of visual information about test letters in bl and blr displays for 1.73 sec, but not for 0.28 sec. In both cases the interpretation was that visual matching was relatively less important for suppressed letters, but the results did not allow the argument to be taken further with confidence to conclude that naming was particularly important for these letters. Indeed, acoustic confusibility may not have produced very much disruption of whatever name comparisons were made. These results are, however, quite consistent with the earlier description of metacontrast suppression as interfering with visual information while sometimes allowing naming, but the effects were weak because the suppression obtained in the displays was itself weak.

Experiment XII : Comparisons of letters presented among other letters

In the previous experiment the task was mainly visual and only weak metacontrast suppression was obtained. In this experiment exactly the same matching task was used but distinguishing the test letter was made more difficult by embedding it in a display of four occurrences of another letter rather than four nonsense forms.

METHOD

All the details of the apparatus, materials and procedure were identical with the previous experiment, except those noted here. The same lists were used, but before a list was presented in any particular session a randomisation program was run to replace all the nonsense forms with letters. In any trial the nonsense forms were all replaced with the same letter, which was randomly chosen but was never the same as either the cue letter or the test letter for that trial. So a typical A trial consisted of the display JGJJJ and the cue letter E. The background letters were re-randomised each time a list was used because they probably contributed considerable variance to the results and there were few displays in the lists for each combination of the independent variables. The effects in the previous experiment had been small and extra variance was expected in this experiment from the variation in background letters, so it was expected that many Ss would be required. Sixteen Ss served for two sessions each.

RESULTS AND DISCUSSION

The analysis was also the same as that of the previous experiment except that in the PRE condition RTs were measured from the display offset rather than from test letter onset, since S always needed to process several letters before locating the test letter. Once again inspection of the data was not sufficient and analyses of variance were conducted. These showed many of the same general results that were found for the matching task with nonsense forms as background: V trials gave slower RTs and higher error rates than A trials in all four main conditions,

there was a tendency for response selection to be delayed until display offset in the PRE condition but it was not complete, and visual confusibility was particularly disrupting when the test letter arrived early in PRE displays.

The analyses revealed, however, no significant interactions with any interesting implications for our study of metacontrast. In particular there were almost no significant interactions involving the A/V factor, although this factor was a significant main effect in all the analyses. Several interactions of interest approached significance and examination of the appropriate means showed patterns similar to those observed in the previous experiment, so, although this experiment does not support the conclusions of Experiment XI, it does not require their qualification either. Also, the variability seemed too large to allow inferences to be drawn from the absence of particular interactions about the different effects of noise-fields and letters as background characters.

As well as making comments about strategies similar to those made in the previous experiment S said that sometimes it was easiest to select the test letter from the display and match it with the cue letter, but sometimes they preferred to identify both letters in the display and compare both with the cue letter. So perhaps it is hardly surprising that any effects were submerged by the variance. The overall error rate in this experiment (10.9%) was only a little more than that in the previous experiment (9.3%) and there was also no marked difference in RT, so the use of a background of letters did not make the task substantially more difficult.

The final approach to the analysis of these two experiments on matching involved analysing the results for the two together. The two methods of measuring the PRE RTs could not reasonably be made comparable, but the POST RT data and the error data for both the PRE and the POST conditions could be combined. The combined analyses showed most of the effects found in each of the experiments alone, sometimes at higher significance levels, but no further effects relevant to metacontrast.

In summary this experiment added nothing to the conclusions of Experiment XI and showed no effects requiring changes in those conclusions; it simply showed that the line of experimental attack adopted is not likely to be fruitful.

8.3 Comparison of Entire Displays

Experiment XIII : Comparisons of entire displays of random letters

The previous two experiments required Ss to match two letters. The task turned out to be mainly visual, it was performed quite accurately and it did not reveal very much about metacontrast suppression. Yet the concept of studying the storage of suppressed letters by manipulating visual and acoustic confusibility remained attractive, so a more difficult matching task was tried. In this experiment Ss had to decide whether two successive displays each consisting of five random letters were the same or were different. In every trial the two displays were either exactly the same or they differed at only one position. Once again acoustic and visual

confusibility were manipulated in the 'different' trials.

METHOD

Twelve experimental lists of 82 trials and two practice lists of 60 trials were prepared. Each trial consisted of two displays of five letters. In half the trials (I trials) the two displays were identical and in the other half (D trials) the two displays differed at just one position, the critical position. No letter ever appeared twice in any single display. In half the D trials the letters at the critical position in the two displays, the critical letters, were acoustically confusable and in the other half they were visually confusable. The trials were called A and V trials accordingly and the A and V pairs used were chosen randomly from the pools of such pairs used in Experiment XI. So a typical V trial was ANGKE, ANGKE and a typical I trial was simple JLP AE, JLP AE. The four display orders used were bl, blr, nb and nbr; they were used equally frequently and the two displays in any trial always had the same display order. The critical position was equally often in each of the five display positions for each display order. There were thus 40 types of D trial; each experimental list consisted of two warm-up trials and then a random ordering of one of each type of D trial together with 40 I trials.

The letter presentation time was 20 msec and SOA was 40 msec. The two displays in a trial were displayed successively and two inter-display intervals were used. In the SHORT condition there

was 0.28 sec from the offset of the first to the onset of the second display and in the LONG condition this interval was 2.5 sec. The shorter interval is that used as the short CI in the two previous experiments while to reduce the amount of visual information available at the end of the delay the longer interval was made longer than the 1.73 sec used previously. The first display in a trial was presented a little above the centre of the scope and the second a little below the centre so that the vertical separation of the centres of the letters in the two displays was 0.9 degrees. The displays were both centred horizontally. The displays were displaced vertically so that the position of the display on the scope would define whether a display was the first or second in a trial and so S, even in a long sequence of trials, should not have become confused and given a response after the first display in a trial. The vertical displacement also meant that matches in the SHORT condition could not be made simply by comparing two closely successive icons in the one place (unless S could make exactly the compensating eye-movement).

Eight Ss served for two sessions. In each session S worked through three SHORT lists and three LONG lists and every group of three lists was preceded by an appropriate practice list. Inter-display interval was always constant within a list, but any of the twelve lists available could be used either as a SHORT or a LONG list. Each S saw each experimental list just once in the experiment. The orders of use of the two intervals and of the twelve lists were counterbalanced over sessions and Ss. The R-S interval was held constant at 1.0 sec. At the end of every list S was told his mean RT and his error rate for that list.

S's task was to give a keypress response to signal 'same' or 'different' after the presentation of the second display in a trial and if in doubt he was to guess. He was instructed to respond as quickly and accurately as possible, but, since the error rate had been very high in the pilot work, accuracy was stressed rather more than speed in the instructions. The 'same' response was always assigned to the right hand key.

RESULTS AND DISCUSSION

All Ss reported that the task was very difficult and taxing and most considered it more so in the LONG than in the SHORT condition. In the LONG condition Ss said that it was difficult both to identify all the letters and to retain those identified in memory. Six of the eight Ss said that they only ever 'saw' (or 'registered', or 'recognised') about 3, or sometimes 4, letters in any display. Three Ss described matching in the SHORT condition as 'automatic' or visual in some way and 4 Ss reported either that they had deliberately adopted a bias towards pressing 'same' when in doubt, or had noticed a tendency to give more 'same' than 'different' responses.

For the analysis the first two trials in each list were discarded and RTs were measured from the first time at which S had sufficient information to make a correct response choice. So in I trials RT was measured from the onset of the last letter presented in the second display and in D trials it was measured from the onset of the critical letter in the second display. RTs less than 150 msec or more than 3000 msec,

or more than three standard deviations from the mean of the remaining RTs of the same type (meaning A or V or I) in the same list were discarded. 2.4% of all RTs were discarded in these ways.

Inspection of the data

Inspection of the results showed that accuracy was low, RTs were long and the variability in RT was large. The overall error rate was 35.6%, but there was a consistent bias towards 'same' responses: the D error rate (S pressed 'same' but was incorrect) was 47.6% while the I error rate was 23.6%, and this bias was a little stronger in the SHORT condition. It is a plausible bias, since even in D trials the display order and four of the five letters in the second display were the same as those in the first, and if S noticed, for example, that three of the letters in the second display were the same as the corresponding three in the first display and he would make no comparison at the other two positions, then his best choice was the 'same' response. The I trials could not, of course, contribute to analyses involving the factors A/V or i, ii/iii, iv. Inspection of the I error rates showed no large variation over inter-display interval (SHORT or LONG) or over display order. The I RTs showed little variation with display order, but were longer in the LONG condition (1031 msec) than in the SHORT condition (800 msec). The I error RTs (974 msec) were consistently longer than correct RTs (859 msec) suggesting that errors were often responses made with low confidence, and that they could not have been corrected. This inference is supported by the universal surprise shown by Ss when told their error rates at the end of each list: they had always greatly under-

estimated their error rate. The D RTs showed a similar pattern: the error RT (1016 msec) was longer than the correct RT (981 msec). These figures also show that responses in I trials were faster than those in D trials, whether or not the response was correct.

This pattern of values may be contrasted with, for example, that found by Bamber (1969). He required Ss to make a same-or-different judgement between two successively presented arrays of up to four letters each. The arrays were either identical, or they differed at only one position. All the letters within any array were presented simultaneously on a card and there was no difficulty seeing them. Bamber found that responses to I trials were faster than those to D trials, but that errors of either type were about as fast as correct 'same' responses, and that most errors could have been corrected. So the much higher error rates, longer RTs, especially long error RTs and the ignorance of Ss of their own errors in the present experiment all emphasize that the difficulties were of perception, encoding and memory, rather than of time pressure while making a match between remembered and seen arrays, as in Bamber's experiment.

Analyses of variance

Four 5-way analyses of variance were applied to the D RTs. Since the error rate was high, for the first time in these experiments sufficient error RTs were available to allow their inclusion in the main analyses. But the number of trials in each cell was too small to permit the bl, blr, nb, nbr factor and the i, ii, iii, iv factor to be classified more finely than into two in each case. So for the

first two analyses the factors were: A(SHORT/LONG); B(Ss); C(V/A); D(bl,blr/nb,nbr); E(i,ii/iii,iv). One of these analyses, (Analysis (1)) was of correct RTs only and the other (Analysis (2)) of error RTs. A single analysis of variance (Analysis (3)) was applied to the D error rates, following an arcsine transformation; the factors were the same as those given above. The final two analyses of the D RTs used as factors: A(Correct/Error); B(Ss); C(V/A); D(bl,blr/nb,nbr); E(i,ii/iii,iv). One of these (Analysis (4)) was applied to SHORT RTs alone and the other (Analysis (5)) was of LONG RTs alone.

The main findings of these analyses will be mentioned and then those of particular relevance to the consideration of metacontrast will be discussed in greater detail. Analyses (1) and (2) showed that LONG RTs (1070 msec) were considerably longer than SHORT RTs (837 msec), while Analysis (3) showed that performance was a little more accurate at the LONG interval (44.5%) than at the SHORT (50.6%). It is plausible that both I and D RTs were longer in the LONG interval lists since there was presumably much more uncertainty about when the second display would arrive in this case. Analysis (2) showed that A error RTs (1041 msec) were a little slower than V error RTs (986 msec) ($p < 0.025$), suggesting that Ss were in general less confident in pressing 'same' incorrectly in an A trial than in a V trial. This is the only hint that visual matching may have been slightly more important than name matching, but there was no interaction with SHORT/LONG and no main effect of V/A in the error analysis, Analysis (5), or any other of the RT analyses.

There was a main effect of E, the temporal display position, in all the analyses except Analysis (3). Early critical letters gave errors much more frequently (60.1%) than did late critical letters (35.0%). If the selection of response was delayed until the offset of the second display the i and ii RTs would have been 60 msec longer than the iii and iv RTs. The observed difference was 142 msec for correct RTs, but only 52 msec for error RTs. These values suggest that correct responses, at least, were made with lower confidence to early than to late critical letters. Analysis (3), of SHORT RTs, confirmed that this tendency was greater for correct than error responses at the SHORT interval ($p < 0.025$).

Findings related to metacontrast

The D RT analyses showed several effects relevant to metacontrast. The only such effect to emerge from Analyses (1) and (2) was shown by the significant ($p < 0.05$) DxE interaction of Analysis (1). Relevant values are given in Table 14a and show that correct RTs to suppressed letters were long and so these critical letters were generally difficult and led to correct responses with low confidence. Although further classification of the D and E factors in the analyses was not possible, separate values are shown in the tables for positions iii and iv of nb and nbr displays. Position iii of these displays is, of course, nb,4 and nbr,2 combined and, since these positions showed some similarities with suppressed positions in earlier experiments, the interest here is in the extent to which results for these positions

resembled those for position i and ii of bl and blr displays.

The AxDxE interaction was significant in Analysis (3) of SHORT RTs ($p < 0.025$) and in Analysis (4) of LONG RTs ($p < 0.05$) and showed in each case that the long RTs to suppressed critical letters occurred, but only for correct and not for error responses. Critical letters in suppressed positions were indeed the only ones for which correct responses were slower than errors; those at nb,4 and nbr,2 did not show the effect. This result might be interpreted by supposing that suppressed positions were difficult and either led to a low confidence, correct, 'different' response or, if suppression was particularly complete, to an incorrect 'same' response of moderate confidence.

The CxDxE interaction of Analysis (3), of SHORT RTs, was significant ($p < 0.025$) and relevant means are shown in Table 14b. The four underlined values are relevant to the significant DxE interaction ($p < 0.05$) mentioned earlier, which suggested that early critical letters gave slower responses when in bl and blr displays than when in nb and nbr displays, for both the A and V conditions. The three-way interaction seems to have been produced by the high value (878 msec) for the A, iii and iv, nb and nbr condition. This high value was in turn largely due to that for the iii position of these trials (906 msec) and so there is some indication here that acoustic confusibility was disruptive for critical letters in the nb,4 and nbr,2 positions, at the SHORT interval.

	<u>bl,blr</u>	<u>nb,nbr</u>
1,ii	1113	1038
iii,iv	891	997 (111: 992) (iv : 962)

Table 14a: Mean correct, D RTs in msec relevant to the DxE interaction of Analysis (1) for Experiment XIII.

<u>bl,blr</u>			<u>nb,nbr</u>		
A	V	mean	A	V	mean
1,ii 964	975	<u>969</u>	917	930	<u>923</u>
iii,iv 822	846	<u>834</u>	878 (111:906) (iv : 852)	831 (111:824) (iv : 838)	<u>855</u> (111:865) (iv : 845)

Table 14b: Mean SHORT, D RTs (correct and errors) in msec relevant to the CxDxE interaction of Analysis (3) in Experiment XIII. The four underlined values show the DxE interaction.

<u>bl,blr</u>			<u>nb,nbr</u>		
A	V	mean	A	V	mean
1,ii 72.2 67.7	<u>70.0</u>		49.6	50.9	<u>50.2</u>
iii,iv 21.8 29.1	<u>25.0</u>		48.6(111:61.8) (iv: 35.4)	40.4(111:49.7) (iv: 31.0)	<u>44.5</u> (111:56.0) (iv: 33.2)

Table 14c: Error percentages, for D trials, relevant to the CxDxE interaction of Analysis (5) in Experiment XIII. The four underlined values show the DxE interaction.

Analysis (5), of error rates, provided the most interesting findings relevant to metacontrast suppression. Both the DxE interaction and the CxDxE interaction were significant ($p < 0.001$ and $p < 0.01$ respectively); the relevant values are shown in Table 14c. The DxE interaction shows that many more D errors were made to trials with suppressed critical letters than to any other trials. (In a D error S pressed 'same' incorrectly; recall that all five analyses being discussed included D trials only.) In bl and blr trials many more errors were made when the critical letter appeared early, while in nb and nbr trials the errors were more evenly spread over the temporal positions. But the separate error rates for iii and iv trials show that the apparently even spread was largely caused by the high error rates for iii trials i.e. for those with critical letters in positions nb,4 or nbr,2. This is a very plausible finding, for the task may be considered as a search for difference: S searched through pairs of displays showing many obvious similarities and pressed 'different' if he detected any indication of a difference. If he saw no such indication he pressed 'same'. On this interpretation it is quite reasonable that so many 'suppressed differences' were missed. It is also interesting that so many differences in the nb,4 and nbr,2 positions were missed as well. Examination of the data for individual Ss showed that the iii error rate was significantly higher than the iv error rate in nb and nbr displays separately for the A and V conditions at each of the SHORT and LONG intervals ($p < 0.05$ or better, in each case, by a two-tailed Wilcoxon test).

The CxDxE interaction extended this result by showing an additional effect of type of confusibility. The pattern of values shown in Table 14c suggests that acoustic confusibility was relatively more disruptive than visual confusibility for positions i and ii of bl and blr trials, compared with iii and iv of these trials, ^{in particular} and that the same was true for position iii, compared with position iv, of nb and nbr trials. So for nb,4 and nbr,2 and possibly for suppressed positions acoustic confusibility disguised a difference relatively more effectively than did visual confusibility, but this effect was small compared with the effect shown by the DxE interaction and discussed in the preceding paragraph. The CxDxE interaction appears to have been produced mainly by the results for the nb and nbr,iii positions and so, although the pattern is consistent with acoustic confusibility being particularly disruptive for suppressed positions, this result cannot be taken as evidence that this is the case.

An interesting aspect of these findings was that Analysis (5) found no interaction with SHORT/LONG interval and so any inferences about the types of comparisons being made apply equally to the 0.28 sec and the 2.5 sec delays.

Comparison of the findings of the present experiment with those of Experiment XI shows several differences. The error rates and RTs in the present experiment were very much higher than in the earlier experiment and so the change from a letter matching to a display matching task was successful in increasing the difficulty of the task. Ss' descriptions of the displays in the two experiments suggested that the phenomenal metacontrast suppression was greater in the present experiment and this is as expected, given the discussion at the end of the report of Experiment XI, since the displays consisted of random letters in the present experiment. Another difference was that the letter matching task appeared to be mainly a visual task, since V error rates and RTs

were considerably greater than those for A trials, but there was no such general tendency in the results for the display matching task. Posner and Taylor (1969) (see also Section 8.1) presented evidence that, if the number of letters in the original array in a successive matching task was increased beyond two, visual codes of the third and subsequent letters were not strongly formed since name matches were just as fast with these letters at all delays from 10 msec to 1500 msec. The difficulty appeared to be at the encoding stage, even though the first array was presented for 1.0 sec. A visual noise-field always followed the first array, so an icon did not contribute to the matching. Considering this result it is reasonable that the matching in the present experiment was not especially visual, since S had five letters to encode in each trial. And if no more than about two letters were coded in visual form even in trials with the short interval, it is also reasonable that no decrease was found in the importance of visual storage from the short to the long interval, as occurred for suppressed letters in Experiment XI. Two letters is probably an under-estimate, however, because the total exposure time of the first display plus the SHORT interval was only 460 msec, much less than the 1000 msec of Posner and Taylor's first array presentation. Ss' reports and the discussion of letter-naming times given by Neisser (1966) both suggested that S could not have read five letters in 460 msec, and so even any imperfect visual information may have been relatively more important than name coding for more than two letters in each trial.

Summary and conclusions

It remains now to draw together and summarise the findings relevant to metacontrast and to discuss what they imply about the processing of suppressed letters. The pattern of general findings fits well with the interpretation that the task was a difficult visual search task in which S searched for any sign of a difference between the two displays in a trial. Error rates were high and were even higher when the critical letter was at a suppressed position. Ss adopted a fairly strict criterion for a difference and so there was a strong response bias towards 'same' and it is reasonable that many differences at suppressed positions were missed. The picture of the task as a difficult one over-loading perceptual, encoding or memory processes, or more than one of these, is completed by the observation that errors were slow, indicating that Ss' confidence was generally low.

Considering only D trials, there was evidence that when the critical letter was suppressed, response was particularly slow, especially for correct responses and especially at the SHORT interval. This did not appear to be the case for the nb,4 and nbr,2 positions, but for these the SHORT RTs were particularly long in A trials.

At these positions, also, relatively more A than V errors were made but there was no clear evidence that this was the case at suppressed positions.

How then were matches made at all? In the SHORT condition S probably could not obtain either visual codes or name codes for all 5 letters in the first display, but the characteristics of the displays, Ss' reports and the short time intervals involved imply that some visual matching was used in the SHORT condition. Similarly, some naming was

~~Handwritten scribbles and illegible text across four lines.~~

CHAPTER 9

Subjective Brightness, Duration and Clarity

Experiment XIV: Ss report what they see by giving numerical ratings of brightness, duration or clarity for each letter in a display. Suppressed letters appear dim and brief, but not blurred.

Chapter 7 started by wondering whether the direct approach of asking S to name the letters in a metacontrast display might be valuable. In this chapter an experiment is described which took another direct approach to the investigation of just what S sees in a metacontrast display. Ss saw displays either many times, to allow careful inspection, or just once, and wrote down in each case a line of five numbers giving subjective estimates of the brightness, duration or clarity of the corresponding five letters.

One particular aim was to study the appearance of letters in the positions nb,4 and nbr,2 , which seem to resemble suppressed letters in some ways ~~but~~ yet are not reported as missing from the displays. It might be possible that they are at least partially suppressed (for Ss usually do under-estimate the total number of letters in nb and nbr displays) but that the missing letter is not located correctly, or at all, because position identification in these displays is particularly difficult. If this is so, and if the position identification problem can be solved, then ratings for these letters should be low.

METHOD

Four experimental lists of 13 displays and one practice list of 8 displays were prepared. Two of the experimental lists were termed pure lists, because each display in the list consisted of several repetitions of a single letter and so was called a pure display. The other two lists were termed mixed lists because each display consisted of several different letters. Repetition was not allowed within a mixed display. The practice list consisted of four pure displays followed by four mixed displays.

The experimental lists each contained four displays which contributed results to the experiment, one having each of the display orders used: bl, blr, nb and nbr. Each of the five letters in these experimental displays was displayed for 6 msec, i.e. it was displayed once in each of two successive display cycles. The experimental displays were distributed randomly through the lists. The remaining displays, called irrelevant displays, also had one of the same four display orders, but in these displays the letters were not all presented for 6 msec. Some letters (never more than one per display) were omitted altogether while others (one or two or three per display) were displayed once in each of four successive cycles and therefore appeared on the scope for about 14 msec. In each list the four display orders were used about equally frequently and in the irrelevant displays letters were omitted or displayed for the long presentation time about equally frequently at the five display positions. To make the structure of the lists quite clear, suppose that

a dash represents a blank i.e. an omitted letter, a letter represents presentation for the normal time and an underlined letter represents presentation for the longer time. Then in the pure lists typical experimental displays were AAAAA and QQQQ and irrelevant displays were G-GGG and BB-BB, while in mixed lists typical experimental displays were LYNZT and PAZFG and irrelevant displays were NJTAE and HRYK-. The SOA was always 40 msec.

S used the same triggering and responding methods as were used in Experiment X, so S pressed a push-button to trigger presentation of the next display and wrote his response on a roll of paper mounted behind a small window. Two viewing conditions were used. In the first, the recycling condition, parameters were set so that presentation of the display was repeated once per second until S's button was pressed for the next display. In the one-look condition a display was presented only once when S pressed the button.

The alphabet used omitted M, O, V and W and consisted of the remaining 22 letters. To reduce the influence of particular letter combinations the letters in the displays were chosen randomly from the alphabet each time a list was used.

When observed on the screen the letters in experimental displays showed the usual effects associated with bl, blr, nb and nbr display orders: there was apparent movement, there were differences in apparent brightness and some letters were not seen. Irrelevant displays, as would be expected, showed similar effects, but in these displays some letters really were absent and there was a variation in physical intensity

as well as in brightness. Irrelevant displays were included in the lists so that S would be rating subjective differences produced by physical differences as well as those caused by metacontrast and so should not have been able to complain that 'what you psychologists do is to present two equal things and have us say they're different' (see Ornstein (1969, Chapter 7) for this quotation and a discussion). The responses given to irrelevant displays, particularly those to blank positions, would also allow some estimation to be made of the extent to which S made errors in identifying the display positions. Ss were, of course, not aware of any classification of displays as experimental or irrelevant, or that only some of the responses would be used in the analysis.

To help S identify the five display positions a white card was positioned against the face of the scope. A rectangle just slightly larger than a five-letter display had been cut out from the card and the card was aligned so that displays could be seen through the hole. Vertical lines were drawn in black ink on the card opposite the five display positions. The lines for positions 1, 3 and 5 were above the hole and those for 2 and 4 below it.

The experiment falls conveniently into three parts; these will be referred to as parts (a), (b) and (c). Part (a) was an exploratory experiment on subjective brightness. Four Ss participated for one session each. They rated only subjective brightness and saw only the recycling condition. After considering their responses parts (b) and (c) were designed and run. In part (b) six different Ss served

for two sessions each. They rated apparent brightness and perceived clarity, and saw the recycling condition in their first session and the one-look condition in their second. In part (c) eight more Ss rated apparent duration and perceived clarity, and they saw also the recycling condition in their first session and the one-look condition in a second session. The experiment was, however, interrupted for a month by failure in the equipment and then it was terminated by a move of the whole installation. So in both parts (b) and (c) one of the Ss served for only one session. Also, Ss' rates of working varied widely and in each of parts (b) and (c) one of the Ss worked so slowly that one session had to remain unfinished and could not be completed later.

The following instructions were read to S at the start of the first session, for brightness (duration) ratings:

This is an experiment to study the appearance of letters flashed very briefly on the screen. You will see displays of five letters and your task is to give your subjective rating of the apparent brightness (duration, or persistence) of each letter in the display. The presentation of a display will be repeated, once per second, over and over again for as long as you like, to allow plenty of time for your inspection and judgement. Your task is to write down a line of five numbers, giving your rating of the appearance

of the letters displayed at the corresponding five positions on the screen. To help you in identifying them, the five display positions are marked by black vertical lines. In making your judgements please use a scale of digits running from 0: nothing whatever seen at this position, to 1: an extremely dim, faint (fleeting, brief, quick) letter, and so on up to 7: a very bright (persistent, long, lingering) letter. You will see the full brightness (duration) range in the first few displays of the practice list so you can use those to standardise your use of the numbers. Please take as much time as you wish and try to be careful and consistent in your ratings.

A suitably modified set of instructions was used at the start of the second session, in which S saw the one-look condition.

In parts (b) and (c) the plan was for S to rate perceived clarity (or sharpness, or definition of the individual dots) in as many lists as he rated brightness or duration, but in every case the S did not work further than the clarity practice list before deciding that clarity was almost constant. This result will be discussed together with the other results, but it did mean that nearly all the time in every session was spent on the rating of brightness or duration. In each session the instructions were read and then S worked through the practice list. In the recycling session S worked through the two mixed and two pure experimental lists once each and in the one-look session S worked through the complete set of four lists twice, with the usual re-randomisation of lists described earlier.

RESULTS AND DISCUSSION

Results for part (a)

The results for part (a) will be considered first. In this part Ss saw only the recycled condition and gave only brightness ratings. Examination of the raw data suggested that Ss used the full scale from nought to seven quite efficiently. The use of nought was analysed for all displays: two Ss used nought when and only when a display contained a blank and it was always in the correct position. One S gave a non-zero number for a blank four times (out of a total of 24 blanks seen by any S) and the fourth S did this nine times and also gave one nought in the wrong position. The accuracy with which nought was used as the rating for a blank seems the best indication available of the difficulty Ss found in identifying the five display positions. These results therefore suggest that the identification of positions was very good, at least for three of the four Ss. The errors which did occur were equally distributed between the nb and nbr and the bl and blr condition, so there is no indication here that Ss were less successful at identifying positions in either of the two types of display.

Considering now only the responses for experimental displays, the bl and blr ratings were as expected for two of the Ss and typical sets of ratings were 52615 and 31423. The other two Ss rated the brightness of all letters in the experimental displays as being nearly the same; typical sets were 65666 and 55443. Ratings for nb and nbr displays showed no such clear pattern for the first two Ss and showed little

variation among letters for the second two. A 'suppression score' was derived for every set of responses. It was simply the mean rating for positions 1, 3 and 5 minus that for positions 2 and 4, and so would be large if suppression was shown by the brightness ratings.

The mean suppression score for bl and blr displays and that for nb and nbr displays were determined for each S. The values were (1.8, 0.8; 1.9, 1.0; 0.6, 0.2; 0.0, -0.2) respectively, for the two conditions for each of the four Ss. So every S gave a higher score for the metacontrast displays, although the last two Ss clearly made little distinction among brightnesses in the experimental displays. There was no sign of any difference between pure and mixed displays. The difference between the scores for the bl and blr condition and the nb and nbr condition was calculated for each of the 16 lists (four for each of 4 Ss). It was positive for 15 of the lists and this is significantly different from the number expected by chance by the appropriate χ^2 test over Ss ($\chi^2_4 = 14.0$, $p < 0.01$). So brightness ratings did show evidence of suppression.

The ratings at positions 2 and 4 were compared within every nb and nbr experimental display to see whether those for the nb,4 and nbr,2 positions were low. The difference was in the predicted direction (i.e. nb,4 and nbr,2 ratings were lower) in eight displays, was zero in 15 displays and was in the opposite direction in nine displays. So the predication was clearly not confirmed. The same was true for the Ss individually.

The two Ss who ratings showed little variation over position may have simply been using a narrow section of the full rating scale, but they seemed to use the whole scale for the irrelevant displays almost as fully as the other Ss. They may rather have interpreted 'apparent brightness' differently. One of Blanc-Garin's findings that was described in Section 2.6 is relevant here. She found that at an inter-stimulus interval of 30 to 75 msec, with a disk-ring metacontrast display, S gave an apparent brightness rating of either the lowest value or of the highest value on the scale, or gave the 'I cannot tell' response.

In the present experiment S saw the same display many times before and while he gave his ratings. The most usual strategy reported was to use the black lines and precise selective fixation to identify a position, give a rating for the letter there and then proceed to the next position. By contrast Blanc-Garin's Ss were required to respond after each single presentation, but the Ss in part (a) may have faced a similar choice between whether, with the highly selective fixation allowed, a letter suppressed by metacontrast was nearly of normal appearance, if considered in isolation, or was nearly not seen at all if considered as part of the display. Since S was not permitted a doubtful or don't-know response he had to choose, and it appears that two Ss leant in one direction and two in the other.

The Ss complained of the difficulty of the task, but could not (and said they could not) describe adequately just what the difficulty was, except to say that it centred on just what they should take to be 'apparent brightness'.

<u>S</u>	Recycled		One-look			
	<u>bl,blr</u>	<u>nb,nbr</u>	Pure		Mixed	
			<u>bl,blr</u>	<u>nb,nbr</u>	<u>bl,blr</u>	<u>nb,nbr</u>
AG	2.0	0.7	-	-	-	-
PK	2.9	0.0	3.0	0.9	2.9	0.2
AL	1.1	0.4	1.5	0.7	1.2	1.1
PM	1.8	0.7	1.3	0.2	3.2	0.1
SC	0.6	0.5	1.7	1.2	2.1	0.9
JH	0.8	0.9	0.6	0.7	1.7	0.3
mean	1.53	0.53	1.62	0.74	2.22	0.52

Table 15: Suppression scores for brightness ratings given by six Ss in part (b) of Experiment XIV.

In summary, part (a) suggested that in the recycling condition S could identify positions, but had difficulty with a working definition of apparent brightness and this showed up in individual differences in the rating of suppressed letters. Even so, the suppression scores for bl and blr displays were significantly higher than those for nb and nbr displays. Finally, there was no sign of ratings at positions nb,4 and nbr,2 being lower than those at positions nb,2 and nbr,4, although the number of responses contributing to the comparison was small.

Part (b): brightness ratings

In part (b) the generally successful arrangements of part (a), recycled displays and brightness ratings, were used once again. After a full session of responses in the recycled condition Ss were asked to give ratings for displays in the one-look condition in their second session. Ss also gave ratings of clarity in both sessions, but those results will be discussed separately later.

Table 15 shows the suppression scores for the six Ss in part (b). Once again scores were consistently higher for bl and blr displays than for nb and nbr displays, although also once again two Ss (S.C. and J.H.) showed little variation over display position in their ratings in the recycling condition. This difference was hardly significant ($\chi^2_6 = 11.3$, $p < 0.10$) for the recycling condition alone. Considering parts (a) and (b) together, suppression scores in the recycling condition were significantly higher for metacontrast displays than for nb and nbr displays ($\chi^2_{10} = 25.3$, $p < 0.01$). There were no signs of any differences in the scores for pure and mixed displays in part (b).

The scores for metacontrast displays were significantly higher in the one-look condition as well, for pure lists ($\chi^2_5 = 13.0, p < 0.025$) and mixed lists ($\chi^2_5 = 17.0, p < 0.005$) separately. All five Ss gave higher bl and blr scores in the one-look than in the recycled condition, but there is no indication that the difference between the scores for the metacontrast displays and for the nb and nbr displays is different in the two cases.

Comparison of the ratings for the nb,4 and nbr,2 positions with those for the nb,2 and nbr,4 positions, for the recycled condition in part (b), showed a consistent and significant ($p < 0.05$, two-tailed) difference in the expected direction. Combination of these results with those for part (a), which by themselves showed no difference, gave an overall difference which just reached the 0.05, two-tailed level. So the ratings for the ten Ss in parts (a) and (b) did show some tendency for the nb,4 and nbr,2 positions to resemble suppressed positions by eliciting low ratings.

Use of the suppression score as a measure of metacontrast suppression relies on S having identified the positions correctly. If identification was not perfect in bl and blr displays then the score probably underestimates the effect. But if position identification in nb and nbr displays was worse than that in bl and blr displays the difference observed in the suppression scores may partly reflect this difference rather than only a metacontrast effect. Once again the ratings given to blanks in the irrelevant displays were analysed to give some indication of the difficulty of position identification. All cases where

a rating of more than zero was given to a blank (including cases where a nought was given among the ratings for a display containing a blank, but in the wrong position) were counted. Only three such errors were made in the recycling condition of part (b), so by this measure position identification in that condition was nearly perfect. In the one-look condition the error rate was much higher. An average of 4.4 such errors occurred in each pure list and 3.2 in each mixed list, out of a total possible of six such errors in any list. So the Ss were in general not good at locating blanks, at least in the one-look condition, even though the positions were marked by black vertical lines. The difference between these error rates for pure and mixed lists suggested that position identification was more difficult in the pure displays: a quite reasonable finding. The comparison could only be made over five Ss, but was just significant ($t = 2.31$, $p < 0.05$, one-tailed). There was no sign of a difference in error rates between the bl and blr condition and the nb and nbr condition, so the difference in suppression scores found between these two conditions may be accepted as a measure of metacontrast suppression.

Considering now that if S had difficulty with position identification the suppression scores would probably have been lowered, the results described above suggest that suppression in the one-look condition may well have been greater than in the recycling condition. Also, it may have been greater for pure than for mixed displays in the one-look condition. But these inferences depend, of course, on the assumption that difficulty in locating blanks indicated general difficulty in identifying positions and although the hypothesis

is quite reasonable this experiment cannot provide evidence in its support.

Comparison of ratings for the nb,4 and nbr,2 positions with those for the nb,2 and nbr,4 positions, in the one-look condition, showed no difference; difficulty in locating positions may account for this result.

Ss in part (b) made comments about the task and the appearance of the displays which were similar to those made in part (a). Understandably, they found the one-look condition particularly difficult and two mentioned that it was difficult to remember enough to give ratings for all five positions after a single presentation. In the one-look condition two Ss found mixed lists easier than pure, because the positions were easier to identify, while one thought pure lists easier because he did not need to waste time identifying the letters. In her first session (with the recycling condition) one S (S.C.) described the difficulty of applying the rating scale to 'some letters which come up early then flick to an adjacent position and there look much more persistent; the early ones are harder to see yet seem to have the same brightness as later ones'. Another S reported that in his second session (with the one-look condition) he sometimes tended to rate letters for their apparent duration, which did vary, rather than their brightness, which seemed more nearly constant.

These last two observations, together with pilot work with other Ss, led to the use of ratings for apparent duration in part (c) of the experiment.

<u>S</u>	Recycled		One-look			
	<u>bl,blr</u>	<u>nb,nbr</u>	Pure		Mixed	
			<u>bl,blr</u>	<u>nb,nbr</u>	<u>bl,blr</u>	<u>nb,nbr</u>
RF	1.9	1.1	1.8	0.3	2.2	0.1
CK	2.4	0.0	-	-	-	-
DD	1.7	1.1	-0.4	0.8	-1.1	0.4
BG	2.1	0.1	2.6	1.2	1.8	0.6
PJ	1.6	0.4	0.9	0.5	2.3	0.6
PA	1.6	1.1	0.9	0.4	1.2	0.7
GB	1.7	0.9	1.2	0.5	2.2	1.2
MC	2.7	1.5	2.1	2.0	2.6	1.4
mean	1.96	0.78	1.30	0.81	1.60	0.71

Table 16: Suppression scores for duration ratings given by the eight Ss in part (c) of Experiment XIV.

Part (c): duration ratings

Part (c) was similar to part (b) except that eight Ss served and they rated the apparent duration, rather than brightness of the letters.

Ss made comments which were similar to those made in parts (a) and (b). In addition, although they had been given the instructions only for apparent duration, four Ss mentioned the difficulty of distinguishing duration from brightness and made comments suggesting that they assumed the two were related and they sometimes rated a composite quality, or that they sometimes inferred duration from brightness.

Table 16 sets out the suppression scores. Once again the scores were greater ($p < 0.001$) for the bl and blr displays than for the nb and nbr displays in the recycling condition. Examination of the ratings suggested that one S (D.D.) had great trouble identifying positions or using the scale consistently, or both. Without her data the difference in scores between the bl and blr displays and the nb and nbr displays in the one-look condition was highly significant, for each of the pure and mixed lists. But with her data included the differences were near the significance borderline.

The analysis of errors in locating blanks in irrelevant displays and the analysis of positions nb,4 and nbr,2 were, in a similar fashion, suggestive but not conclusive. As in part (b) hardly any errors in the location of blanks were made in the recycling condition (except by D.D.), but many were made in the one-look condition. Again more were made in the pure than in the mixed lists, but the difference did not reach significance. The comparison of ratings at positions nb,4 and nbr,2 with those at nb,2 and nbr,4 showed a difference in the expected direction for six of the eight Ss in the recycling condition, but the

difference did not reach significance. There was no sign of a difference in the one-look condition.

So the pattern of results for duration ratings resembled that for brightness ratings, but data from more Ss would be required to establish the effects unequivocally.

Clarity

In parts (b) and (c) Ss were asked to rate the clarity (or sharpness or definition of the individual dots) of the letters in the displays, in just the same way as they were asked to rate brightness or duration, although never more than one quality was rated in any one list. In the first session they saw the recycling condition and in the second the one-look condition. The practice list was given and by the end of this S invariably claimed that clarity did not vary at all. When pressed to find variation three of the fourteen Ss said in one or other of their sessions that the dots in brighter letters looked less well defined than in other letters, one said just the opposite and one thought that the end letters in the displays looked a little clearer than the middle letters. The conclusion in every case had to be that metaccontrast suppression does not change the clarity of letters. This is in direct disagreement with Mayzner's reports of the informal descriptions given by his observers, which were discussed in Chapter 3.

Summary

Although the Ss were not experienced at using rating scales and although the number of Ss used was not large, the experiment clearly showed that metacontrast suppression does occur. There were individual differences in the pattern of ratings which suggested variation in the interpretation of 'apparent brightness' when rating suppressed letters. Suppression was shown most clearly by ratings of brightness and duration in the recycling condition. In the one-look condition suppression was measured to be at least as great, but position identification was more difficult in this case and so the subjective effect may have been underestimated; it may have been greater in the one-look than in the recycling condition. Similar reasoning suggested that it may have been greater for pure than for mixed displays in the one-look case. There was no sign of any change in the judged clarity of letters with metacontrast suppression or apparent movement in the displays.

Comparison of ratings for the nb,4 and nbr,2 positions with those for the nb,2 and nbr,4 positions, in the recycling condition, suggested that ratings were lower at the nb,4 and nbr,2 positions; these were the positions which resembled suppressed letters in some previous experiments. But the effect was small, and did not appear in the ratings for the one-look condition.

In summary, the experiment showed that suppressed letters are indeed hard to see and that the difficulty may be described as a brightness reduction or an apparent duration reduction, but not as a reduction in clarity.

CHAPTER 10

Coda

The experimental results. Their implications for Mayzner's theory. Final summary and conclusions.

10.1 The Experimental Results

In this section the experimental results of the last five chapters will be reviewed and then in the following sections they will be considered together with Mayzner's model and other ideas about visual processing.

The results of Chapter 5 were clear-cut and simple: suppressed characters can initiate and control either a simple or a choice motor response. This is the case whether a simple O/X discrimination or a more complicated digit/letter discrimination is required and whether S is working under pay-offs for speed or for accuracy. It is true even for the first hour or two of practice. Metaccontrast suppression is thus unlike physical dimming at least in its effect on motor response times.

Searching through a display of five random letters looking for a single target letter involves rather different perceptual analyses from those required to make a classificatory decision about the whole display. For example all letters in the display would often have to be scanned whereas only the first letter presented need be analysed before making a classification of the whole display. In Chapter 6 the results of three experiments using a visual search task were reported. The general finding was that suppressed targets are detected with fair but not complete efficiency. If S adopted a strict criterion for a target

then the detection rate for suppressed targets dropped, in the conditions used, from 95% to 70%. The effects were overlaid by increased miss rates for targets in the later temporal positions when S adopted a set for speed and therefore made many premature target absent responses. Allowing for this, suppressed targets were detected a little less efficiently than other targets when β was low (S's criterion was lax) and much less efficiently when β was high. In Experiment VI^a ^{high} d' for the detection of suppressed targets was associated with a lax criterion for a target and also with fast target detection RTs.

The rather different conditions used in Experiments VII and VIII showed no further evidence of fast performance actually increasing the efficiency of detection of suppressed targets and the point was not taken further in later work.

The first phenomenological descriptions of metacontrast suppression were simply that some letters were not seen. Chapters 5 and 6 presented evidence that these letters can be analysed quite fully by the perceptual system if an appropriate task is chosen. In Chapter 7 descriptions were given of the experiments requiring S to identify some or all of the letters in the displays, and so the task was more similar to phenomenological report than were the tasks used in the Experiments of Chapters 5 and 6. The largest effect was simply that Ss found it difficult to identify and report suppressed letters. There were general experimental

problems of fixation and position identification, but even so, performance was worst for suppressed letters. The second result was that, if position intrusion error responses were excluded, the remaining errors, item errors, were more likely to be acoustically confusable with the corresponding correct letter if the correct letter had been suppressed. In Experiment X the effect was small, but it was consistent and highly significant. It was inferred that S relies relatively more on name coding for suppressed letters than for other letters and consequently that visual information in particular is lost for these letters and also that the letters must often have been named before the visual information is lost. This loss of visual information is presumably precisely what meta-contrast suppression is, and the result suggests that naming is sometimes achieved before the suppression occurs.

In Chapter 8 an attempt was made to discover in what form or forms a suppressed letter is represented in memory, if it is represented in memory at all. In Experiment XI S made a same-or-different comparison between a cue letter and a test letter and the acoustic and visual confusibility of the letters was varied. The task was found to be mainly visual, but the results suggested that visual information about suppressed letters was ^{at least partially lost} ~~within~~ within 1.75 sec but not 0.28 sec after display offset. This visual information may have been in the form of an icon or a Posner-type code; this point is mentioned below (see p.292). A more difficult task was used in Experiment XIII: S made matches between two successive displays, each of five letters. The major finding was that S had difficulty retaining the full five letters from the first display for comparison with the second and that this difficulty was particularly great for suppressed letters. So once again these letters were found to be

hard to see.

Evidence for the existence of the phenomenon investigated, metacontrast suppression, came first from subjective descriptions of the displays. An attempt was made in Experiment XIV, described in Chapter 9, to study the appearance of the displays in a better controlled way. Ss gave ratings of the brightness, apparent duration and clarity of letters in displays which were either seen many times, or only once. In both cases suppressed letters were judged to be less bright and of shorter duration than other letters, but no less sharply defined than other letters. Position identification was, understandably, much more difficult in the one-look than in the recycled condition and so results from the two conditions could not be easily compared. But there was some indirect evidence suggesting that the judged brightness and duration difference between the suppressed and other letters was greater in the one-look than in the recycled displays.

Several of the experiments gave results suggesting that the nb,4 and nbr,2 positions resemble positions 2 and 4 of bl and blr displays. Chapter 5 could, of course, give no evidence of the capacity of letters in these positions to control a simple or choice response since they do not appear in the first temporal position in the nb and nbr orders. Experiment VIII showed that targets in these positions are missed as

frequently as suppressed targets when S's criterion is strict. Experiment X showed the proportion of item errors at these positions which were acoustic confusions is also high. The results for the matching task of Experiment XIII also suggested that ^{acoustic confusibility is particularly important at} the nb,4 and nbr,2 positions. ~~~~~~~~~ Finally, although letters in the nb,4 and nbr,2 positions are not described as apparently missing from the displays, there was some evidence in the results of Experiment XIV that these letters are judged as appearing less bright and of shorter duration than others. They are followed on one side by a letter presented 80 msec later, so it is plausible that they may suffer some suppression.

10.2 The results considered together.

Considering only optics and the fact that suppressed letters appear first in time in the bl and blr displays, it is clear that a visual image of the letters arrives at the retina and starts on the way up the visual system. It is also clear from the results and from descriptions of the displays that usual full perception of the shape of the letters is not achieved. So we have remaining to us the task of analysing the nature and the time-course of the loss. The loss is clearly primarily visual in nature. The appearance of the displays suggests that it is at least a visual loss and Chapters 7 and 8 provided evidence that it is specifically a visual loss. It is also in keeping with the experimental and theoretical work in the whole field of visual masking discussed in Chapter 2 that the interactions ^{between} among stimuli are considered peripheral in the sense that they depend on shape rather than names or meaning and that it is visual information that is removed. It is more difficult to take the argument further

and decide the nature of the visual loss. It may be, for example, the loss of the icon, or of the visual code studied by Posner and his associates. This point will be considered later.

Turning to the time course of the loss, it is clear that sufficient analysis is accomplished to control a choice response before the loss occurs. This is the case even when S must discriminate letters from digits and when accuracy is stressed. It might be argued that the discussion should be in terms of a slight partial loss occurring very early, rather than a more complete loss later in time. But this assumes that the letter-digit discrimination, which is accomplished efficiently, is considerably less complex than letter recognition, which is found very difficult; this is not clearly so. It would also be expected that if the digit-letter discrimination were made on degraded input then some increase in the amount of error or in the response time would follow, yet none at all was found in the quite sensitive experiments of Chapter 5. The final difficulty for the counter-argument is the point stated in the preceding paragraph: we know that the suppressed letters make normal progress through the very early stages of the visual system simply because they appear alone on the screen before any other letters are presented.

Assuming now that metacontrast suppression is primarily a degradation of visual information some time after input, what are the implications for deeper recoding processes? The obvious first point is that since input is only visual any deeper coding must follow later in time and must be directly or indirectly a recoding of visual information. Deficiencies of other types of information may be observed but may only reflect the underlying visual degradation. Taking a more positive approach, if

recoding of the visual information can be achieved sufficiently quickly a letter might be able to survive its impending suppression even if not in visual form. The making of a simple or choice motor response to a suppressed character may be considered in this way: the relevant information about the letter escapes suppression because at the critical time it is stored as, perhaps, a set of muscle commands about to be executed. In the letter identification experiments of Chapter 7 some suppressed letters were reported correctly and so presumably had been named and remembered satisfactorily. But the result that more item errors were acoustic confusions for suppressed than for other letters emphasises that even though visual information was removed some recoding into a name form had been accomplished sufficiently early for some name information about the letter to be available to guide the response.

In these terms the perceptual analysis required in the visual search task of Chapter 6 could be carried out sufficiently quickly for nearly as many suppressed as other targets to be detected. At least, this was the case when S's criterion for a target was lax. If S adopted a strict criterion many more suppressed targets were missed and this might indicate that a slower, more detailed analysis was used in this case. It might equally well mean that S required not only some indication that a target was present from the early, fast analysis of all the letters in the display, but also that some indication was still present a little later when a response choice was being made. These two formulations are probably not really distinct and are much the same as saying that S undertook some rechecking for a target when the criterion was strict. In each case visual information had to be present for longer and so more suppressed targets

failed the lengthened test and were missed. The result in Experiment VI, that Ss giving shorter target detection RTs were actually more efficient at detecting suppressed targets leads to a similar interpretation, once again supporting the theory that visual information is available for recoding, for a short time, and then is lost.

10.3 The Relationship with Mayzner's ideas

The nature of perception

If letters can be saved from suppression by fast, early recoding, then can they be 'seen' if the appropriate analysis is applied early enough? Bruner (1957) discussed early ideas about perception and in particular the debate about whether pure perception can be separated from perception depending on memory traces and past experience, or indeed whether pure perception exists at all. He argued forcefully that 'all perceptual experience is necessarily the end product of a categorisation process' and that 'if perceptual experience is ever had raw, i.e. free of categorical identity, it is doomed to be a gem serene, locked in the silence of private experience'. So we should expect categorisation to precede perception. It is only a small further step to postulate that if an input can be categorised it is perceived. On the operational definition that perception has occurred when an appropriate response can be made, the suppressed letters in the classification tasks of Chapter 5 were not only categorised but perceived, since S nearly always pressed the correct key. But can these letters be perceived in the sense that S reports, 'I see it'?

Some evidence that this can happen was provided by Experiment XIV. Some Ss, in the recycling condition when prolonged inspection and selective fixation were encouraged, did rate suppressed letters as being similar in appearance to other letters. A further relevant observation was made as the experimental work proceeded but has not yet been reported. (It has not, however, been reported by Mayzner and his colleagues although they have been studying metacontrast phenomena for several years.) It is simply that the subjective suppression effect is reduced by long practice and familiarity. The writer, after two years' work with the displays, finds the effect no longer compelling; there is still a definite apparent brightness difference, but all letters can usually be named fairly easily, and so suppressed letters would never be described as 'not seen'. This change with long practice was not observed in the experiments because in no case did an S participate in an experiment for more than four sessions; the aim had been to find a few reliable methods of measuring suppression and then to run a small number of Ss for many sessions each, looking for changes in suppression over sessions, but the work did not progress sufficiently quickly to allow this. Mollon (1969) reported a large decrease in threshold for TS detection over sessions in a visual masking task and showed that it was not simply produced by selective attention in time, since the improvement still occurred with randomised foreperiods. Informal observations of displays at unpredictable times extend this result to the metacontrast suppression of letters being investigated here. The improvement presumably results from learning of a perceptual strategy which allows a suppressed letter to be categorised sufficiently quickly and well to be named confidently. Having been named it will hardly be described as

'not seen', even if brightness ratings would still show evidence of suppression.

Short term storage

For our operational definition in terms of the 'I see it' response we must require that a letter is not only categorised, but remembered for a second or two. In other words S must not only see the letter but must remember that he saw it for long enough to say so. The response 'I see it' is, presumably, usually made when visual information is available for at least a certain minimum time. As postulated in the preceding paragraph it might also be made if a suppressed letter is categorised sufficiently confidently and the categorisation is remembered. This type of 'I see it' response would thus be like a target detection in the visual search task, with a strict criterion. That the criterion is strict is plausible since S would be saying 'I see it' without the usual abundance of bright visual information and his response might seem to him to be 'I didn't see anything and it was a G'. (This may be contrasted with the situation discussed in Section 2.7 which gives opposite results: S reports that letters in an array followed by a visual noise-field appear relatively clear and bright and of high contrast, but still only very few of the letters can be named.)

Perceptual organisation

In considering the second situation leading to the 'I see it' response it is relevant to recall the discussion in terms of organisation given in Section 2.5 when metacontrast was being considered. Toch (1956) observed that if in the classic three-squares metacontrast display a second square was added one square's width to the left of the square which was TS, the new TS was not suppressed but the perception of the whole display was organised as that of a pair of squares moving from left to right. In Chapter 8, in connection with the matching experiments, a discussion of the metacontrast suppression of letters was sketched in similar terms. Now Mayzner's observations suggested that suppression did not occur very strongly in displays in which the letters in the otherwise suppressed positions were sufficiently different in shape from the other letters, but that it did occur in displays consisting of random letters. So ABABA would show less suppression than ALXCP. Homogeneous displays (AAAAA) were also described as showing more suppression than displays consisting of random letters (ALXCP). But, as noted in Chapter 3, Mayzner's theory that suppression arises from interactions among analysers that are very shape specific does not explain why suppression in ALXCP is stronger than that in ABABA, or even why it occurs at all. An interpretation in terms of organisation can, however, handle all the observations simply by supposing that only in the case of ABABA are the letters in positions 2 and 4 sufficiently distinct to be not only categorised but also remembered. Random letters should probably be considered more easily labelled individually than letters in a homogeneous display, so it is reasonable that suppression

is somewhat stronger in homogeneous displays. Our theory that suppressed letters can elicit the 'I see it' response if first they are categorised and then the categorisation is preserved fits well with this discussion in terms of organisation. The argument suggests that if we are interested primarily in the degradation of visual information produced by metacontrast then brightness ratings are a more appropriate measure than 'I see it' reports. For example, Experiment XIV found only slim, indirect evidence that suppression as measured by differences in brightness ratings was any greater in pure than in mixed displays.

If the 'I see it' response can follow from a sufficiently confident categorisation even in the presence of a brightness reduction, then the use of this response in the study of metacontrast has two interesting implications. First, the categorisation used by S can be changed by changing the response required, or even by S simply adopting a different set or strategy. So metacontrast measured in this way should change accordingly. Second, we have argued that the perceptual organisation given to a display can affect the categorisation made and, in particular, the success with which the categorisation of a suppressed letter can be retained. Apparent movement is a compelling form of organisation for the elements in a display, if they are arranged appropriately. So it is reasonable that metacontrast and apparent motion should often appear related and that some displays giving good apparent motion should not show metacontrast suppression.

Subjective visual experience.

The 'I see it' response has been assumed to follow either if sufficient visual information is available, or if a sufficiently confident categorisation can be made and retained. If this is the case the introduction of SVE (subjective visual experience i.e. consciousness) is misleading since either it corresponds only to the first of these two situations, in which case a letter might not have reached SVE yet still be reported as seen, or it corresponds exactly to the 'I see it' response and so makes no distinction between these two situations leading to this single response. Mayzner chose the second of these courses and took the SVE concept to correspond to the 'I see it' response. This may or may not be useful if the aim is to satisfy introspections about consciousness, but appears less useful for the study of metacontrast suppression since the primary effect, the change in apparent brightness, is confused with secondary information processing implications of this change. In other words, the division of situations into those in which letters reach SVE and elicit the 'I see it' response and those in which they do not groups together letters which are seen brightly and those which suffer suppression but which are categorised sufficiently well to be remembered. It does not place the dividing line between letters which suffer some brightness reduction and those which do not, but rather between those which are categorised sufficiently confidently to lead to the 'I see it' response and those which are categorised less confidently, but which still can elicit, for example, a normal choice motor response.

A theory of metacontrast suppression aimed at explaining when and how subjective brightness is decreased by metacontrast probably should invoke only fairly peripheral processes, such as were considered in the review of masking and metacontrast given in Chapter 2. However, in choosing to build a model for the 'I see it' response, instead of brightness reduction, and yet still invoke only such peripheral interactions, Mayzner may have an impossible task. The difficulties for the model are just those described in Chapter 3 and they arise when a suppressed letter can be categorised quickly and well, such as when it is part of a suppressed word. It might well lead to the 'I see it' response, but it is much more in keeping with current ideas about information processing in visual perception to suppose that visual information is available for a short time before suppression occurs rather than to require that meaning controls the operation of the peripheral interactions assumed to underlie metacontrast. Word recognition in displays in which every letter of the word is in a suppressed position is probably the most promising task to use in the next experiments aimed at confirming the interpretation of metacontrast suppression given here.

Brightness suppression

Brightness suppression undoubtedly does occur, however, and we should consider what it is and how it might occur. Experiment XIV suggests directly that the loss of visual information may be seen or interpreted as a reduction in apparent brightness or apparent duration, but not as a smearing or reduction in clarity. Experiment XI found that visual con-

fusibility was disrupting for matches to suppressed test letters made about 400 msec after test letter presentation, but not for matches made about 1900 msec after test letter presentation. This result might suggest that a visual code, of the type investigated by Posner, was still available after 400 msec. Even so, this visual code had a shorter life for suppressed than for other letters and so it is not possible to decide whether suppression acts by degrading this visual code or the icon relatively more. Both of these types of visual storage are formed very quickly after input and certainly before suppression takes place, so presumably both are degraded, but we cannot tell whether either is affected more, or sooner than the other.

Considering the nature of the interaction there are three points we can make. First, the argument of this section implies that in considering the brightness reduction we need not consider naming or meaning, and so the discussion of Section 2.5 applies equally to the metacontrast observed in displays of letters. We are no nearer to understanding why or how it occurs; Mayzner's postulated interactions between excitation and inhibition in shape analysers seem a reasonable guess for the present, but for the reasons discussed above his restriction to interactions among very form-specific analysers should be weakened.

The second point is that the type of metacontrast being studied here consists of interactions among letters close together in time and space and so it is appropriate to recall the discussion of masking of form by form given in Section 2.4. The two main theories were the integration and confusion theory and the read-out and erasure theory. The conclusion

was that the confusion theory must be weakened to allow some read-out of the first form before the second is presented, that the erasure theory cannot apply unless the second form is much stronger than the first, and that then the two apparently quite different theories might indeed be indistinguishable. The interaction which reduces the brightness of one letter when adjacent letters are presented later in time is certainly nothing like the integration and confusion of the letters, but might be considered a partial erasure of one by the others, where erasure is taken to be a reduction in brightness but not in perceived clarity. Simply saying so is hardly explanatory, but it encourages us not to abandon entirely the erasure formulation of masking of an array by a noise-field and it suggests that the theoretical explanations of the two phenomena might need to be related.

Third, by studying displays of letters and using several different information processing tasks we have found evidence that metacontrast suppression occurs only after the analysis of the letters concerned has been proceeding for a short time. Considering also the first point above, this conclusion must apply to the usual metacontrast situations, which are discussed in Section 2.5. Except for the triggering of a simple motor response to display onset, as studied by Fehrer and Raab (1962), perceptual analyses are not usually available in these situations to demonstrate that TS is available for processing for a short time immediately after presentation. If appropriate tasks could be devised, however, we would expect that they would show evidence of the availability of TS for a short time before suppression.

This conclusion is probably the main contribution this whole investigation can make to the general study of metacontrast. It implies that a complex analysis may be applied to TS if the analysis is very fast, and so it disagrees with for example the interpretation of Rumelhart (1970) (see Section 2.4; p.46). Rumelhart supposed that features are read-out serially from the icon of TS and that a criterion number (C) of features must be read-out before any particular task may be accomplished. The value of C depends on the nature of the task and is larger for tasks requiring more complex perceptual analyses. So simple analyses, such as that required to trigger a simple motor response, have a low C and may be carried out on masked stimuli, whereas insufficient features can be read-out to allow a complex analysis of a masked stimulus to be made. Our theory, on the other hand, says that in metacontrast displays a large number of features might be available at first, but then lost unless coded and stored so as to escape suppression.

10.4 Summary and Conclusions

The experiments reported in this thesis gave two main findings. First, the observation that suppressed letters are hard to see was confirmed by several experiments which used a variety of tasks and showed that these letters are indeed difficult to process in many situations. The difficulty was found to be caused by a loss of specifically visual information and the suppressed letters were judged less bright and of shorter duration but of the same clarity as other letters. The second finding was that suppression of a letter only occurs

after it has been available for analysis for a short time. If S can apply a suitable perceptual analysis to the letter sufficiently quickly then some information about the letter may be preserved and an appropriate response given, or S may even say 'I see it', although brightness ratings would still reveal an effect of suppression.

The conclusion that suppressed letters can elicit the 'I see it' response if they are coded sufficiently confidently suggested that Mayzner's theory centred on SVE confounded seeing because of abundant information with seeing because of confident categorisation. It would be more appropriate to study the brightness change, which is the primary result produced by metacontrast suppression, directly by using brightness ratings. Theories may then be sought in terms of fairly peripheral interactions in the visual system, just as they are for normal metacontrast phenomena.

Finally, the finding that items are available for analysis for a short time immediately after input, before suffering suppression, illustrates the value of using complex stimuli, i.e. letters, and information processing tasks investigated in other areas of psychology in the study of visual masking and metacontrast. The result also applies to the usual metacontrast displays and implies that TS is available for a short time before being suppressed, even if there are usually no analyses, except that for display onset as Fehrer and Raab (1962) discovered, which can take advantage of its availability then.

References

- Adkins, J.W., Fehmi, L.G. & Lindsley, D.B. (1969). Perceptual discrimination in monkeys: retroactive visual masking. Physiol. Behav. 4, 253-259.
- Alpern, M. (1952). Metaccontrast: Historical introduction. Am.J.Optom. 29, 631-646.
- Alpern, M. (1953). Metaccontrast. J.opt.Soc.Am. 43, 648-657.
- Alpern, M. and David, H. (1959). The additivity of contrast in the human eye. J. gen. Physiol. 43, 109-126.
- Andreassi, J.L., Mayzner, M.S., Beyda, D. and Waxman, J. (1970). Sequential blanking: a U-shaped function. Psychon. Sci. 18, 319-321.
- Asher, H. (1950). Contrast in eye and brain. Br. J. Psychol. 40, 187-194.
- Averbach, E. and Coriell, A.S. (1961). Short term memory in vision. Bell. Syst. Tech. J. 40, 309-328.
- Averbach, E. and Sperling, G. (1961). Short term storage of information in vision. In Information Theory (C. Cherry, ed.) Butterworths, London, 196-211.
- Baker, H.D. (1953). The instantaneous threshold and early dark adaptation. J. opt. Soc. Am. 43, 798-803.
- Baker, H.D. (1955). Some direct comparisons between light and dark adaptation. J. opt. Soc. Am. 45, 839-844.
- Baker, H.D. (1963). Initial stages of light and dark adaptation. J. opt. Soc. Am. 53, 98-103.
- Bamber, D. (1969). Reaction times and error rates for same different judgements of multidimensional stimuli. Percept. and Psychophys. 6, 169-174.

- Barlow, H.B. & Hill, R.M. (1963). Evidence for a physiological explanation of the waterfall phenomenon and figural aftereffects. Nature 200, 1345-1347.
- Battersby, W.S. & Defabough, G.L. (1969). Neural limitations of visual excitability: after-effects of subliminal stimulation. Vis. Res. 9, 757-768.
- Battersby, W.S. and Sturr, J.F. (1970). Neural limitations of visual excitability IX. Monocular and interocular changes of sensitivity during flicker stimulation. J. opt. Soc. Am. 60, 121-126.
- Battersby, W.S. and Wagman, I. (1962). Neural limitations of visual excitability IV. Spatial determinants of retrochiasmal interaction. Am. J. Physiol. 203, 359-365.
- Blakemore, C. and Campbell, F.W. (1969). On the existence of neurones in the human visual system selectively sensitive to the orientation and size of retinal images. J. Physiol. 203, 237-260.
- Blanc-Garin, J. (1965). Quelques problèmes posés par l'étude du phénomène de metacontraste visuel. Psychologie Française 10, 147-154.
- Blanc-Garin, J. (1966). Les relations temporelles dans le masquage latéral visuel. L'Année psychologique 66, 365-381.
- Blanc-Garin, J. (1967). Le masquage visuel rétroactif. L'Année psychologique 67, 153-193.
- Blanc-Garin, J. (1968). Divers aspects d l'interférence dans le phénomène de masquage latéral. Vision Res. 8, 509-523.
- Blanc-Garin, J. (1969). L'interaction spatio-temporelle des données de la perception visuelle. PhD. thesis, Sorbonne, Paris.
- Blanc-Garin, J., Dubrocard, S. and Harlay, F. (1970). Construction d'échelles d'estimation pour deux dimensions sensorielles visuelles: problèmes méthodologiques. Cahiers de Psychologie 13, 39-52.

- Boies, S.J. (1963). Rehearsal of visual codes of single letters. Unpublished M.A. thesis, University of Oregon.
- Boynton, R.M. (1958). On-responses in the human visual system as inferred from psychophysical studies of rapid adaptation. A.M.A. Archives of Ophthalmology 60, 800-810.
- Boynton, R.M. (1961). Some temporal factors in vision. In Sensory Communication (W.A. Rosenblith, ed.), Cambridge, MIT press.
- Boynton, R.M. (1962). Spatial vision. Ann. Rev. Psychol. 13, 171-200.
- Boynton, R.M. and Kandel, G. (1967). On-responses in the human visual system as a function of adaptation level. J. opt. Soc. Am. 47, 275-286.
- Boynton, R.M. and Miller, N.D. (1963). Visual performance under conditions of transient adaptation. Illuminating Engineer, 58 541-550.
- Boynton, R.M. and Siegfried, J.B. (1962). Psychophysical estimates of on-responses to brief light flashes. J. opt. Soc. Am. 52, 720-721.
- Brindley, G.S. (1970). Physiology of the retina and visual pathway. (2nd Edition) Edward Arnold Ltd., London.
- Broadbent, D.E. (1971). Decision and Stress. London, Academic.
- Broadbent, D.E. and Gregory, M.H.P. (1971). Effects on tachistoscopic perception from independent variation of word probability and letter probability. Acta Psychol. 35, 1-14.
- Bruner, J.S. (1957). On perceptual readiness. Psychol. Rev. 64, 123-152.
- Bryden, M.P. (1968). Symmetry of letters as a factor in tachistoscopic recognition. Am. J. Psychol. 81, 513-524.
- Buchsbaum, W.H. and Mayzner, M.S. (1969). The effects of line length on sequential blanking. Psychon. Sci. 15, 111-112.

- Campbell, F.W. and Kulikowski, J.J. (1966). Orientation selectivity of the human visual system. J. Physiol. 187, 437-445.
- Campbell, F.W. and Robson, J.G. (1968). Application of Fourier analysis to the visibility of gratings. J. Physiol. 197, 551-566.
- Cattell, J. McK. (1935). The influence of the intensity of the stimulus on the length of the reactiontime. Brain 8, 512-515.
- Cattell, J. McK. (1936). The time taken up by cerebral operations. Mind 11, 277-292, 524-533.
- Cheatam, P.G. (1952). Visual percept^{ual} latency as a function of stimulus brightness and contour shape. J. exp. Psychol. 43, 369-380.
- Cohen, G. (1969). Some evidence for parallel comparisons in a letter recognition task. Q. J. exp. Psychol. 21, 272-279.
- Coltheart, M. (1971). Visual feature-analysers and aftereffects of tilt and curvature. Psychol. Rev. 78, 114-121.
- Conrad, R. (1964). Acoustic confusions in immediate memory. Br. J. Psychol. 55, 73-84.
- Cornsweet, T.N. (1970). Visual perception. Academic.
- Cox, S.I. and Dember, W.N. (1970). Backward masking of visual targets with internal contours. Psychon. Sci. 19, 255-256.
- Crawford, B.H. (1947). Visual adaptation in relation to brief conditioning stimuli. Proc. Roy. Soc. (London) B 134, 283-302.
- Cumming, G.D. (1969). LINC-8: The sophisticated tachistoscope. Paper presented to the DECUS Fifth European Seminar, Stockholm, September 1969, and published in the Proceedings.
- Cumming, G.D. (1971). LINC-8 presents and controls visual experiments. Behav. Res. Meth. & Instru. 3, 24-29.

- Dainoff, M. (1970). Time course of visual and auditory encoding. J. exp. Psychol. 86, 214-224.
- Dainoff, M. and Haber, R.N. (1967). How much help do repeated presentations give to recognition processes? Percept. Psychophys. 2, 131-136.
- Dainoff, M. and Haber, R.N. (1970). Effect of acoustic confusibility on levels of information processing. Can. J. Psychol. 24, 98-108.
- Day, R.H. and Strelow, E.R. (1971). Visual after-effect of movement: partial or complete reduction in the absence of a patterned surround. Nature 230, 55-56.
- Dember, W.N. and Purcell, D.G. (1967). Recovery of masked visual targets by inhibition of the masking stimulus. Science 157, 1335-1336.
- De Valois, R.L. (1966). Neural processing of visual information. In Frontiers in physiological psychology (R.W. Russell, ed.) Academic.
- Diamond, A.L. (1960). A theory of depression and enhancement in the brightness response. Psychol. Rev. 67, 188-199.
- Dick, A.O. and Dick, S.O. (1969). An analysis of heirarchical processes in visual perception. Can. J. Psychol. 23, 203-211.
- Dixon, N.F. (1971). Subliminal perception: the nature of a controversy. McGraw-Hill, London.
- Dodwell, P.C. and Standing, L.G. (1970). Studies of visual backward masking and a model for the Crawford effect. Acta Psychol. 32, 31-47.
- Donchin, E. (1967). Retroactive visual masking: effects of test flash duration on the masking interval. Vision Res. 7, 79-87.

- Donchin, E. and Lindsley, D.B. (1965). Visual evoked response correlates of perceptual masking and enhancement. Electroenceph. clin. Neurophysiol. 19, 325-335.
- Donchin, E., Wicke, J.D. and Lindsley, D.B. (1963). Cortical evoked potentials and perception of paired flashes. Science 141, 1285-1286.
- Doost, R. and Turvey, M.T. (1971). Iconic memory and central processing capacity. Percept. Psychophys. 9, 269-274.
- Efron, R. (1970). The minimum duration of a percept. Neuropsycholog. 8, 57-63.
- Egeth, H. (1967). Selective attention. Psychol. Bull. 67, 41-57.
- Eichelman, W.H. (1968). Letters as units of processing in a visual matching task. Unpublished M.A. thesis, University of Oregon.
- Engelking, E. and Poos, F. (1924). Ueber die Bedeutung des Stereophänomens für die isochrome und heterochrome Helligkeitsvergeichung. Année Psychol. 26, 469-471. (Abstract).
- Eriksen, C.W. (1966). Temporal luminance summation effects in backwards and forward masking. Percept. and Psychophys. 1, 37-92.
- Eriksen, C.W., Becker, B.B. & Hoffman, J.E. (1970). Safari to masking land: a hunt for the elusive U. Percept. and Psychophys. 8, 245-250.
- Eriksen, C.W. and Collins, J.F. (1964). Backward masking in vision. Psychon. Sci. 1, 101-102.
- Eriksen, C.W. and Collins, J.F. (1965). Reinterpretation of one form of forward and backward masking in vision. J. exp. Psychol. 70, 343-351.
- Eriksen, C.W. and Collins, J.F. (1967). Some temporal characteristics of visual pattern perception. J. exp. Psychol. 74, 476-484.

- Eriksen, C.W. and Collins, J.F. (1968). Sensory traces versus the psychological moment in the temporal organization of form. J. exp. Psychol. 77, 376-382.
- Eriksen, C.W. and Collins, J.F. (1969). The temporal course of selective attention. J. exp. Psychol. 80, 254-261.
- Eriksen, C.W., Collins, J.F. and Greenspon, T.S. (1967). An analysis of certain factors responsible for nonmonotonic backward masking functions. J. exp. Psychol. 75, 500-507.
- Eriksen, C.W. and Hoffman, M. (1963). Form recognition at brief durations as a function of adapting field and interval between stimulations. J. exp. Psychol. 66, 485-499.
- Eriksen, C.W. and Lappin, J.S. (1964). Luminance summation - contrast reduction as a basis for certain forward masking effects. Psychon. Sci. 1, 313-314.
- Eriksen, C.W. and Marshall, P.H. (1969). Failure to replicate a reported U-shaped visual masking function. Psychon. Sci. 15, 195-196.
- Eriksen, C.W. and Rohrbaugh, J. (1970). Visual masking in multielement displays. J. exp. Psychol. 83, 147-154.
- Eriksen, C.W. and Spencer, T.J. (1968). Visual search under conditions of very rapid sequential input rates. Percept. Psychophys. 4, 197-202.
- Eriksen, C.W. and Steffy, R.A. (1964). Short term memory and retroactive interference in visual perception. J. exp. Psychol. 68, 423-434.
- Estes, W.K. and Taylor, H.A. (1966). Visual detection in relation to display size and redundancy of critical elements. Percept. Psychophys. 1, 9-16.

- Fehmi, L.G., Adkins, J.W. and Lindsley, D.B. (1969). Electrophysiological correlates of visual perceptual masking in monkeys. Exp. Brain Res. 7, 299-316.
- Fehrer, E. (1965). The contribution of perceptual segregation to the relationship between stimulus similarity and backward masking. Percept. Mot. Skills 21, 27-33.
- Fehrer, E. (1966). Effects of stimulus similarity on retroactive masking. J. exp. Psychol. 71, 612-615.
- Fehrer, E. and Biederman, I. (1962). A comparison of reaction and verbal report in the detection of masked stimuli. J. exp. Psychol. 64, 126-130.
- Fehrer, E. and Raab, D.H. (1962). RT to stimuli masked by metacontrast. J. exp. Psychol. 63, 143-147.
- Fehrer, E. and Smith, E. (1962). Effects of luminance ratio on masking. Percept. Mot. Skills 14, 243-253.
- Fidell, L.S. (1970). Orientation specificity in chromatic adaptation of human 'edge-detectors'. Percept. and Psychophys. 8, 235-237.
- Fitzgerald, R.E. and Kirkham, R. (1966). Backward visual masking as a function of average uncertainty of the masking pattern. Psychon. Sci. 6, 469-470.
- Fraisse, P. (1968). Motor and verbal reaction time to words and drawings. Psychon. Sci. 12, 235-236.
- Fraisse, P. (1969). Why is naming longer than reading? Acta Psychol. 30, 96-103.
- Freeman, P.R. (1964). Table of d' and β . A.P.U. pamphlet 529/64, Cambridge.
- Fry, G. (1934). Depression of the activity aroused by a flash of light by applying a second flash immediately afterwards to adjacent areas of the retina. Am. J. Physiol. 108, 701-707.

- Galbraith, G.C. and Heath, R.G. (1970). Backward visual masking during direct brain stimulation in man. Vision Res. 10, 911-915.
- Garner, W.R., Hake, H.W. and Eriksen, C.W. (1956). Operationism and the concept of perception. Psychol. Rev. 63, 149-159.
- Garner, W.R. and Morton, J. (1969). Perceptual independence: definitions, models and experimental paradigms. Psychol. Bull. 72, 233-259.
- Gibbon, J. and Ritschman, R. (1969). Temporal order judgement and reaction time. Science 165, 413-414.
- Greenspon, T.S. and Eriksen, C.W. (1968). Interocular non-independence, Percept. and Psychophys. 3, 93-96.
- Grossberg, M. (1968). The latency of response in relation to Bloch's law at threshold. Percept. and Psychophys. 4, 229-232.
- Grossberg, M. (1970). 'Backward masking' of simple detection latencies. Percept. and Psychophys. 8, 308-312.
- Gunneman, K. (1970). Knowledge of alternatives and perception of tachistoscopic stimuli. J. exp. Psychol. 83, 335-390.
- Haber, R.N. (1966). Nature of the effect of set on perception. Psychol. Rev. 73, 335-351.
- Haber, R.N. (1970). Note on how to choose a visual noise mask. Psychol. Bull. 74, 373-376.
- Haber, R.N. and Nathanson, L.S. (1969). Processing of sequentially presented letters. Percept. Psychophys. 5, 359-360.
- Haber, R.N. and Standing, L. (1968). Clarity and recognition of masked and degraded stimuli. Psychon. Sci. 13, 83-84.
- Haber, R.N. and Standing, L.G. (1969a). Location of errors with a post-stimulus indicator. Psychon. Sci. 17, 345-346.
- Haber, R.N. and Standing, L.G. (1969b). Direct measures of short term visual storage. Q. J. exp. Psychol. 21, 43-54.

- Haber, R.N. and Standing, L.G. (1970). Direct estimates of the apparent duration of a flash. Can. J. Psychol. 24, 216-229.
- Harcum, E.R. (1970a). Defining shape for perceptual element-position curves. Psychol. Bull. 74, 362-372.
- Harcum, E.R. (1970b). Perceptibility gradients for tachistoscopic patterns: sensitivity or salience? Psychol. Rev. 77, 332-337.
- Harris, C.S. and Gibson, A.R. (1968). Is orientation-specific colour adaptation in human vision due to edge detectors, afterimages or dipoles? Science 162, 1506-1507.
- Harrison, K. and Fox, R. (1966). Replication of RT to stimuli masked by metacontrast. J. exp. Psychol. 71, 162-163.
- Hayes, W., Robinson, J. and Brown, L. (1961). An effect of past experience on perception: An artifact. Amer. Psychologist 16, 420 (Abstract).
- Hays, W.L. (1963). Statistics. Holt, Rinehart and Winston, N.Y.
- Heckenmueller, E. and Dember, W.N. (1965). A forced-choice indicator for use with Werner's disc-ring pattern in studies of backward masking. Psychon. Sci. 3, 167-168.
- Henson, V.A.C. (1911). The relation of the time of a judgement to its accuracy. Psychol. Rev. 18, 186-201.
- Higginson, G.D. (1926). Apparent visual movement and the Gestalt. J. exp. Psychol. 9, 228-252.
- Hochberg, J. (1966). In the mind's eye. In Contemporary Theory and Research in Visual Perception. (R.N. Haber, ed.) Holt Rinehart and Winston,, N.Y. 1963. 309-331.
- Hogben, J. (1971). Interaction of forward and backward visual masking. Percept. and Psychophys. 9, 487-488.
- Houlihan, K. and Sekuler, R.W. (1968). Contour interaction in visual masking. J. exp. Psychol. 77, 281-285.

- John, E.R., Herrington, R.N. and Sutton, S. (1967). Effects of visual form on the evoked response. Science 155, 1439-1442.
- Kahneman, D. (1964). Temporal summation in an acuity task at different energy levels - a study of the determinants of summation. Vision Res. 4, 557-566.
- Kahneman, D. (1965). Exposure duration and effective figure-ground contrast. Q. J. exp. Psychol. 17, 308-314.
- Kahneman, D. (1966a). Time-intensity reciprocity under various conditions of adaptation and backward masking. J. exp. Psychol. 71, 543-549.
- Kahneman, D. (1966b). Time-intensity reciprocity in acuity as a function of luminance and figure-ground contrast. Vision Res. 6, 207-215.
- Kahneman, D. (1967a). An onset-onset law for one case of apparent motion and metaccontrast. Percept. and Psychophys. 2, 577-584.
- Kahneman, D. (1967b). Temporal effects in the perception of light and form. In Models for the perception of speech and visual form. (W. Wathen-Dunn, ed.), MIT press, 157-170.
- Kahneman, D. (1968). Method, findings and theory in studies of visual masking. Psychol. Bull. 70, 404-425.
- Kahneman, D. and Norman, J. (1964). The time-intensity relation in visual perception as a function of the observer's task. J. exp. Psychol. 68, 215-220.
- Kahneman, D., Norman, J. and Kubovy, M. (1967). Critical duration for the resolution of form: centrally or peripherally determined? J. exp. Psychol. 73, 323-327.
- Kaswan, J. and Young, S. (1963). Stimulus exposure time, brightness and spatial factors as determinants of visual perception. J. exp. Psychol. 65, 113-123.
- Keele, S.W. and Chase, W.G. (1967). Short-term visual storage. Percept. Psychophys. 2, 383-386.
- Keitzman, M.L., Boyle, R.C. and Lindsley, D.B. (1971). Perceptual masking: peripheral versus central factors. Percept. Psychophys. 9, 350-352.

- Kellogg, W.N. (1931). The time of judgement in psychometric measures. Am.J. Psychol. 43, 65-86.
- Kelly, D.H. (1969). Flickering patterns and lateral inhibition. J. opt. Soc. Am. 59, 1361-1369.
- Kelly, D.H. (1970). Effects of sharp edges on the visibility of sinusoidal gratings. J. opt. Soc. Am. 60, 98-103.
- Kelly, D.H. (1971). Theory of flicker and transient responses, I. Uniform fields. J. opt. Soc. Am. 61, 537-546.
- Kinsbourne, M. and Warrington, E.K. (1962a). The effect of an after-coming random pattern on the perception of brief visual stimuli. Q. J. exp. Psychol. 14, 223-234.
- Kinsbourne, M. and Warrington, E.K. (1962b). Further studies on the masking of brief visual stimuli by a random pattern. Q.J. exp. Psychol. 14, 235-245.
- Kolers, P.A. (1962). Intensity and contour effects in visual masking. Vision Res. 2, 277-294.
- Kolers, P.A. (1963). Some differences between real and apparent movement. Vision Res. 3, 191-206.
- Kolers, P.A. (1964). The illusion of movement. Scientific Amer. October, 1964
- Kolers, P.A. and Rosner, B. (1960). On visual masking (metaccontrast): dichoptic observation. Am.J.Physiol. 73, 2-21.
- Kornfeld, G.H. and Lawson, W.R. (1971). Visual perception models. J. Opt. Soc. Am. 61, 811-820.
- Liss, P. (1968). Does backward masking by visual noise stop stimulus processing? Percept. and Psychophys. 4, 328-330.
- Mackworth, J.F. (1962). The visual image and the memory trace. Can. J. Psychol. 16, 55-59.
- Mackworth, J.F. (1963a). The duration of the visual image. Can. J. Psychol. 17, 62-81.

- Rackworth, J.F. (1963b). The relation between the visual image and post-perceptual immediate memory. J. verb. Learn. verb. Behav. 2, 75-85.
- Martin, L. (1962). Binocular summation at the absolute threshold of peripheral vision. J. opt. Soc. Am. 52, 1276-1286.
- Martin, L. (1968). Critical duration, the differential luminance threshold, critical flicker frequency and visual adaptation: a theoretical treatment. J. opt. Soc. Am. 58, 404-414.
- Matteson, H.H. (1970). Effects of surround luminance on perceptual latency. J. opt. Soc. Am. 60, 1125-1131.
- Matthews, M.L. (1968). Some temporal aspects of visual spatial interactions associated with illumination gradients. Nature 218, 1061-1063.
- Mayzner, M.S. (1968). The research potential of a computer-based cathode-ray tube display system. Behav. Res. Meth. & Instru. 1, 41-43.
- Mayzner, M.S. (1970). The disinhibited effect in sequential blanking. Psychon. Sci. 20, 213-219.
- Mayzner, M.S., Abrevaya, E.L., Frey, R.E., Kaufman, H.G. and Schoenberg, K.M. (1964). Short term memory in vision: A partial replication of Aveblich and Coriell. Psychon. Sci. 1, 225-226.
- Mayzner, M.S., Blatt, M.H., Buchsbaum, W.H., Friedel, R.T., Goodwin, P.E., Kancn, D., Keleman, A. and Nilsson, W.D. (1965). A U-shaped backward masking function in vision: a partial replication of the Weisstein and Haber study with two ring sizes. Psychon. Sci. 3, 79-80.
- Mayzner, M.S. and Tresselt, M.E. (1966). Studies in sequential perception: looking at one thing but finding another. Percept. Mot. Skills 23, 257-268.
- Mayzner, M.S. and Tresselt, M.E. (1969). Sequential blanking: a function of geometric analysers in the human visual system. Psychon. Sci. 17, 77-78.
- Mayzner, M.S. and Tresselt, M.E. (1970a). Visual information processing with sequential inputs: a general model for sequential blanking, displacement and overprinting phenomena. Ann. N.Y. Ac. Sci. 169, 599-618.

- Mayzner, M.S., Tresselt, M.E., Adrignolo, A.J. and Cohen, A. (1967). Further preliminary findings on some effects of very fast sequential input rates on perception. Psychon. Sci. 7, 281-282.
- Mayzner, M.S., Tresselt, M.E. and Cohen, A. (1966). Preliminary findings on some effects of very fast sequential input rates on perception. Psychon. Sci. 6, 513-514.
- Mayzner, M.S., Tresselt, M.E. and Helfer, M.S. (1967a). A research strategy for studying certain effects of very fast sequential input rates on the visual system. Psychon. Monog. Supp. 2 (5). Whole no. 21. 73-81.
- Mayzner, M.S., Tresselt, M.E. and Helfer, M.S. (1967b). A provisional model of visual information processing with sequential inputs. Psychon. Monog. Supp. 2 (7). Whole no. 23. 91-103.
- Maxwell, A.E. (1961). Analysing qualitative data. Methuen & Co. Ltd., London.
- McCullough, C. (1965). Colour adaptation of edge detectors in the human visual system. Science 149, 1115-1116.
- Mewhort, D.J.K., Merikle, P.M. and Bryden, M.P. (1969). On the transfer from iconic to short term memory. J. exp. Psychol. 81, 89-94.
- Mollon, J.D. (1969). Temporal factors in perception. Unpublished D.Phil. thesis, University of Oxford.
- Natsoulas, T. (1967). What are perceptual reports about? Psychol. Bull. 67, 249-272.
- Neisser, U. (1963). Decision-time without reaction-time: Experiments in visual scanning. Am. J. Psychol. 76, 376-385.
- Neisser, U. (1964). Visual search. Scientific Am. 210, 94-102.
- Neisser, U. (1966). Cognitive Psychology. Appleton-Century-Crofts, N.Y.
- Neisser, U., Novick, R. and Lazar, R. (1963). Searching for ten targets simultaneously. Percept. Mot. Skills 17, 955-961.
- Onley, J.W. and Boynton, R.M. (1962). Visual responses to equally bright stimuli of equal luminance. J. opt. Soc. Am. 52, 934-940.
- Ornstein, R.E. (1969). On the experience of time. Penguin Education, London.

- Bantle, A. and Sekuler, R. (1969). Contrast response of the human visual mechanism sensitive to orientation and direction of motion. Vision Res. 9, 397-406.
- Parlee, M.B. (1969). Visual backward masking of a single line by a single line. Vision Res. 9, 199-205.
- Piéron, H. (1914). Recherches sur les lois de variation des temps de latence sensorielle en fonction des intensités excitatrices. Année Psychol. 20, 17-96.
- Piéron, H. (1925). Recherches expérimentales sur la marge de variation du temps de latence de la sensation lumineuse (par une méthode de masquage). 1'Année Psychol. 26, 1-30.
- Pollack, I. (1971). Temporal anagrams: word identification with successively presented letters in scrambled order. Percept. and Psychophys. 9, 430-434.
- Pollack, R.H. (1965). Effects of figure-ground contrast and contour orientation in figural masking. Psychon. Sci. 2, 369-370.
- Posner, M.I. (1970). Abstraction and the process of recognition. In Advances in learning and motivation, Vol. III. (Spence, J. and Bower, G., Eds.).
- Posner, M.I., Boies, S.J., Eichelman, W.H. and Taylor, R.L. (1969). Retention of visual and name codes of single letters. J. exp. Psychol. Monogr. (Suppl. 1) 79, 1-16.
- Posner, M.I. and Keele, S.W. (1967). Decay of visual information from a single letter. Science 158, 137-139.
- Posner, M.I. and Konick, A.F. (1966). Short-term retention of visual and kinaesthetic information. Org. Behav. Hum. Perfor. 1, 71-86.
- Posner, M.I. and Mitchell, R.F. (1967). Chronometric analysis of classification. Psychol. Rev. 74, 392-409.
- Posner, M.I., and Taylor, R.L. (1969). Subtractive method applied to separation of visual and name components of multiletter arrays. Acta Psychol. 30, 104-114.

- Purcell, D.G. and Dember, W.N. (1968). The relation of phenomenal brightness reversal and re-reversal to backward masking and recovery. Percept. and Psychophys. 3, 290-293.
- Raab, D., Fehrer, E. and Herzshenson, M. (1961). Visual reaction time and the Broca-Sulzer phenomenon. J. exp. Psychol. 61, 193-199.
- Rabbitt, P.M.A. (1964). Ignoring irrelevant information. Br. J. Psychol. 55, 403-414.
- Rabbitt, P.M.A. (1966). Errors and error-correction in choice-response tasks. J. exp. Psychol. 71, 264-272.
- Rabbitt, P.M.A. (1969). Idiosyncrasies of performance in serial RT tasks. Paper presented at the Symposium on Temporal Aspects of Information Processing, XIX International Congress of Psychology, London.
- Rabbitt, P.M.A. (1971). Times for the integration of information and the selection of responses. In preparation.
- Rabbitt, P.M.A. and Vyas, S. (1970). An elementary preliminary taxonomy for errors in laboratory choice RT tasks. Acta Psychol. 33, 56-76.
- Ratliff, F. (1961). Inhibitory interaction and the detection and enhancement of contours. In Sensory Communication (W.A. Rosenblith, ed.), Cambridge, MIT press.
- Ratliff, F. (1965). Mach Bands. Quantitative studies on neural networks in the retina. Holden Day, San Francisco.
- Ratliff, F., Hartline, H.K. and Miller, W.H. (1963). Spatial and temporal aspects of retinal inhibitory interaction. J. opt. Soc. Am. 53, 110-120.
- Reicher, G.M. (1968). Perceptual recognition as a function of meaningfulness of stimulus material. Technical report no. 7, U. of Mich. Hum.perf. Center.
- Reicher, G.M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. J. exp. Psychol. 81, 275-280.
- Robinson, D.N. (1966). Disinhibition of visually masked stimuli. Science 154, 157-158.
- Robinson, D.N. (1968). Visual disinhibition with binocular and interocular presentations. J. opt. Soc. Am. 58, 254-257.

- Robinson, D.N. (1971). Backward masking, disinhibition and hypothesized neural networks. Percept. and Psychophys. 10, 33-35.
- Roufs, J.A.J. (1963). Perception lag as a function of stimulus luminance. Vision Res. 3, 81-91.
- Rumelhart, D.E. (1970). A multicomponent theory of the perception of briefly exposed visual displays. J. math. Psychol. 7, 191-218.
- Scharf, B, and Lefton, L.A. (1970). Backward and forward masking as a function of stimulus and task parameters. J. exp. Psychol. 84, 331-338.
- Scharf, B., Zarnansky, H.S. and Brightbill, R. (1966). Word recognition with masking. Percept. Psychophys. 1, 110-112.
- Schiller, P.H. (1965a). Metacontrast interference as determined by method of comparisons. Percept. Mot. Skills. 20, 279-285.
- Schiller, P.H. (1965b). Monoptic and dichoptic visual masking by patterns and flashes. J. exp. Psychol. 69, 193-199.
- Schiller, P.H. (1966). Forward and backward masking as a function of relative overlap and intensity of test and masking stimuli. Percept. and Psychophys. 1, 161-164.
- Schiller, P.H. (1968). Single unit analysis of backward visual masking and metacontrast in the cat lateral geniculate nucleus. Vision Res. 8, 855-866.
- Schiller, P.H. and Chover, S.L. (1968). Metacontrast: its relation to evoked potentials. Science 153, 1398.
- Schiller, P.H. and Greenfield, A. (1969). Visual masking and the recovery phenomenon. Percept. and Psychophys. 6, 182-184.
- Schiller, P.H. and Smith, M.C. (1965). A comparison of forward and backward masking. Psychon. Sci. 3, 77-78.
- Schiller, P.H. and Smith, M. (1966). Detection in metacontrast. J. exp. Psychol. 71, 32-46.
- Schiller, P.H. and Smith, M. (1968). Monoptic and dichoptic metacontrast. Percept. and Psychophys. 3, 237-239.
- Schiller, P.H. and Wiener, M. (1963). Monoptic and dichoptic visual masking. J. exp. Psychol. 66, 386-393.

- Schoenberg, K.M., Katz, M. and Mayzner, M.S. (1970). The shape of inhibitory fields in the human visual system. Percept. Psychophys. 7, 337-359.
- Schurman, D.L. and Colegate, R.L. (1970). Dark intervals as stimulus events and their effect on visual masking and time-intensity reciprocity. J. exp. Psychol. 85, 278-287.
- Schurman, D.L. and Eriksen, C.W. (1969). Summation and interaction of successive masking stimuli in visual perception. Am. J. Psychol. 82, 320-332.
- Schurman, D.L., Eriksen, C.W. and Rohrbaugh, J. (1968). Masking phenomena and time-intensity reciprocity for form. J. exp. Psychol. 73, 310-317.
- Sekuler, R.W. (1963). Spatial and temporal determinants of visual backward masking. J. exp. Psychol. 70, 401-406.
- Sekuler, R.W. and Pantle, A. (1967). A model for after-effects of seen movement. Vision Res. 7, 427-439.
- Selfridge, O.G. (1959). Pandemonium: A paradigm for learning. In The mechanisation of thought processes, London, H.M.S.O.
- Sherrick, M.F. and Dember, W.N. (1970a). Visual backward masking and the area-detection relation. Psychon. Sci. 19, 127-128.
- Sherrick, M.F. and Dember, W.N. (1970b). Completeness and spatial distribution of mask contours as factors in visual backward masking. J. exp. Psychol. 84, 179-180.
- Smith, F. and Carey, P. (1966). Temporal factors in visual information processing. Can. J. Psychol. 20, 337-342.
- Smith, M.C. and Schiller, P.H. (1966). Forward and backward masking: a comparison. Can. J. Psychol. 20, 191-197.
- Spencer, T.J. (1969). Some effects of different masking stimuli in iconic storage. J. exp. Psychol. 81, 132-140.
- Spencer, T.J. and Shuntich, R. (1970). Evidence for an interruption theory of backward masking. J. exp. Psychol. 85, 198-203.
- Sperling, G. (1960a). The information available in brief visual presentations. Psychol. Monogr. 74 (Whole No. 498).
- Sperling G. (1960b). Bistable aspects of monocular vision. J. opt. Soc. Am. 50, 1140-1141.

- Sperling, G. (1963). A model for some kinds of visual memory tasks. Hum. Factors 5, 19-31.
- Sperling, G. (1963). Temporal and spatial visual masking I: Masking by impulse flashes. J. opt. Soc. Am. 55, 541-549.
- Sperling, G. (1967). Successive approximations to a model for short term memory. Acta Psychol. 27, 285-292.
- Sperling, G. (1970). Model of visual adaptation and contrast detection. Perceptl and Psychophys. 8, 143-157.
- Sperling, G. (1971). Information retrieval from two rapidly consecutive stimuli: a new analysis. Percept. Psychophys. 9, 89-91.
- Sperling, G. and Sondhi, M.M. (1968). Model for visual luminance discrimination and flicker detection. J. opt. Soc. Am. 58, 1133-1145.
- Standing, L.G., Haber, R.N., Cataldo, M. and Sales, B.D. (1969). Two types of short-term visual storage. Percept. Psychophys. 5, 193-196.
- Sternberg, S. (1966). High-speed scanning in human memory. Science 153, 652-654.
- Sternberg, S. (1967). Two operations in character-recognition: Some evidence from reaction-time measurements. Percept. Psychophys. 2, 45-53.
- Stewart, A.L. and Purcell, D.G. (1970). U-shaped masking functions in visual backward masking: effects of target contiguity and retinal position. Percept. Psychophys. 7, 253-256.
- Stewart, A.L., Purcell, D.G. and Dember, W.N. (1968). Masking and recovery of target brightness. Proceedings of the 76th Annual Convention of the APA, 109-110.
- Strobelow, E.R. and Day, R.H. (1971). After-effect of visual movement: storage in the absence of a patterned surround. Percept. Psychophys. 9, 485-486.
- Sturr, J.F. and Battersby, W.S. (1966). Neural limitations of visual excitability VIII. Binocular convergence in cat geniculate and cortex. Vision Res. 6, 401-418.
- Sturr, J.F. and Frumkes, T.E. (1968). Spatial factors in masking with black or white targets. Percept. Psychophys. 4, 282-294.

- Sutherland, N.S. (1959). Stimulus analysing mechanisms. In Mechanisation of thought processes. Vol. II, H.M.S.O., London.
- Sutherland, N.S. (1961). Figural after-effects and apparent size. Q.J. exp. Psychol. 13, 222-228.
- Sutton, S. (1970a). The sensitivity of the evoked potential to psychological variables. Paper presented to the EEG Society, Washington.
- Sutton, S. (1970b). Correspondence between the psychological and physiological threshold. Paper presented to the A.P.A., Miami.
- Swets, J.A. (ed.) (1964). Signal detection and recognition by human observers. Wiley, N.Y.
- Teuber, H.L., Battersby, W.S. and Bender, M.B. (1960). Visual field defects after penetrating missile wounds of the brain. Cambridge, Mass., Harvard Univ. Press.
- Thomas, J.P. (1970). A model of the function of receptive fields in human vision. Psychol. Rev. 77, 121-134.
- Thompson, J.H. (1966). What happens to the stimulus in backward masking? J. exp. Psychol. 71, 580-586.
- Toch, H.H. (1956). The perceptual elaboration of stroboscopic presentations. Am. J. Psychol. 69, 345-358.
- Treisman, A. (1962). Binocular rivalry and stereoscopic depth perception. Q.J. exp. Psychol. 14, 23-36.
- Treisman, A.M. (1969). Strategies and models of selective attention. Psychol. Rev. 76, 282-299.
- Tresselt, M.E. and Mayzner, M.S. (1969). Estimates of 'SVE' processing time. Psychon. Sci. 16, 103-104.
- Tresselt, M.E., Mayzner, M.S., Schoenberg, K.M. and Waxman, J. (1970). A study of sequential blanking and overprinting combined. Percept. Psychophys. 8, 261-264.
- Turvey, M.T. (1967). Repetition and the preperceptual information store. J. exp. Psychol. 74, 289-293.
- Turvey, M.T. and Kravetz, S. (1970). Retrieval from iconic memory with shape as the selection criterion. Percept. Psychophys. 8, 171-172.

- Uttal, W.R. (1963). Do compound evoked potentials reflect psychological codes? Psychol. Bull. 64, 377-392.
- Uttal, W.R. (1969). Masking of alphabetic character recognition by dynamic visual noise (DVN). Percept. Psychophys. 6, 121-128.
- Uttal, W.R. (1970a). On the physiological basis of masking with dotted visual noise. Percept. Psychophys. 7, 321-327.
- Uttal, W.R. (1970b). Violations of visual simultaneity. Percept. Psychophys. 7, 133-136.
- Uttal, W.R. (1970c). Masking of alphabetic character recognition by ultrahigh-density dotted visual noise. Percept. Psychophys. 7, 19-22.
- Uttal, W.R. (1971a). The effect of interval and number of masking with dot bursts. Percept. Psychophys. 9, 469-473.
- Uttal, W.R. (1971b). The physiological silly season - or - What happens when neurophysiological data become psychological theories. J. gen. Psychol. 84, 151-166.
- Vaughan, H.G., Costa, L.D. and Gilden, L. (1966). The functional relation of the visual evoked response and reaction time to stimulus intensity. Vision Res. 6, 645-656.
- Vaughan, H.G. and Silverstein, L. (1968). Metacntrast and evoked potentials: a reappraisal. Science 160, 207-208.
- Von Wright, J.M. (1968). Selection in visual immediate memory. Q.J. exp. Psychol. 20, 62-68.
- Wagman, I.H. and Battersby, W.S. (1959). Neural limitations of visual excitability II. Retrochiasmal interaction. Am. J. Physiol. 197, 1237-1242.
- Weisstein, N. (1966). Backward masking and models of perceptual processing. J. exp. Psychol. 72, 232-240.
- Weisstein, N. (1968). A Rashevsky-Landahl neural net: simulation of metacntrast. Psychol. Rev. 75, 494-521.

- Weisstein, N. (1969). What the frog's eye tells the human brain: single cell analysers in the human visual system. Psychol. Bull. 72, 157-176.
- Weisstein, N. (1971). W-shaped and U-shaped functions obtained for monoptic and dichoptic disk-disk masking. Percept. Psychophys. 9, 275-278.
- Weisstein, N. and Growney, R.L. (1969). Apparent movement and meta-contrast: a note on Kahneman's formulation. Percept. Psychophys. 5, 321-323.
- Weisstein, N. and Haber, R.N. (1965). A U-shaped masking function in vision. Psychon. Sci. 2, 75-76.
- Weisstein, N., Jurkens, T. and Onderisin, T. (1970). Effect of forced-choice versus magnitude-estimation measures on the waveform of metacontrast functions. J. opt. Soc. Am. 60, 978-980.
- Werner, H. (1938). Studies on contour I: Qualitative analysis. Am. J. Psychol. 47, 40-64.
- Werner, H. (1940). Studies on contour: Strobostereoscopic phenomena. Am. J. Psychol. 53, 418-422.
- Wheeler, D.D. (1970). Processes in word recognition. Cog. Psychol. 1, 59-85.
- Wicke, J.D., Donchin, E. and Lindisey, D.B. (1964). Visual evoked potentials as a function of flash luminance and duration. Science 146, 83-85.
- Wickelgren, W.A. (1965). Distinctive features and errors in short-term memory for English vowels. J. Acoust. Soc. Am. 38, 583-588.
- Wickelgren, W.A. (1966). Distinctive features and errors in short-term memory for English consonants. J. Acoust. Soc. Am. 39, 388-398.
- Wickelgren, W.A. and Whitman, P.T. (1970). Visual very-short-term memory is nonassociative. J.exp. Psychol. 84, 277-281.

- Wilding, J.M. (1970). Unpublished Ph.D. thesis, University College, London.
- Wilding, J.M. (1971). The relation between latency and accuracy in the identification of visual stimuli. I The effects of task difficulty. II The effects of sequential dependencies. Acta Psychol. (in press).
- Wilson, J.A. and Anstis, S.M. (1969). Visual delay as a function of luminance. Am.J.Psychol. 82, 350-358.
- Winnick, W.A. and Daniel, S.A. (1970). Two kinds of response priming in tachistoscopic recognition. J. exp. Psychol. 84, 74-81.
- Wolford, G.L., Wessel, D.L. and Estes, W.K. (1968). Further evidence concerning scanning and sampling assumptions of visual detection models. Percept. Psychophys. 3, 439-444.