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TEMPORAL INTEGRATION IN VISION

by

LEON MICHAEL GOLD

Thesis submitted for the
Ph.D. degree

CITY UNIVERSITY (LONDON)
DEPARTMENT OF SOCIAL SCIENCE
AND HUMANITIES

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DECLARATION

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ABSTRACT

Methods of measuring visual persistence are discussed with particular reference to partial report (PR) and temporal integration (TI) techniques. The current categorization of information persistence as exemplified by PR methods and visible persistence, which is purportedly demonstrated by "direct" methods of investigation, is critically examined. A survey is conducted of various "direct" investigations and it is pointed out that differing techniques do not always generate concordant results. Moreover, certain anomalies that are exposed by TI techniques are difficult to explain with conventional notions about visible persistence.

Two variations of the Eriksen and Collins paradigm are used to test a proposal that lexical and pattern-only collages would give rise to differential temporal effects. This idea was not supported but effects due to following field duration (Sd2), which have been largely overlooked in recent TI literature, were found to be robust.

A visual masking investigation as well as further TI studies are used to investigate the Sd2 function in greater depth. A tentative hypothesis for TI operations, which involved perceptual segregation of iconically stored information, was proposed. This idea included the possibility that perceptual integration is limited by two processes, one of these being the gradual loss of persisting visual information.

Predictions from this hypothesis are validated in studies which compare the effects of the Sd2 parameter on backward masking and integration. The other process that limited integration was tentatively identified to be a tendency towards perceptual dissociation (as distinct from perceptual segregation).

It is argued that a consequence of this hypothesis could be that the differences between PR and TI might become reconciled. A PR approach is used to investigate this. Temporal effects, not usually associated with this paradigm, were obtained under certain circumstances. Moreover, two types of transposition error, which are predicted by the dissociation hypothesis, were identified.

A tentative model of temporal integration and its consequences for immediate short term visual memory is outlined and critically discussed.

CHAPTER 1: AN HISTORICAL PERSPECTIVE AND REVIEW OF CURRENT RESEARCH

1.1 Introduction

When two short visual displays are presented sequentially, separated by a brief temporal gap, they often appear to overlap so that they can be seen in a merged percept. This phenomenon is known as temporal integration. The generally held view about it is that visual information about the leading stimulus can persist for a time after its physical offset (this is known as visual persistence). This information can then combine with a visual stimulus that appears a short time later so that a collage is perceived.

Modern psychological interest in this phenomenon has usually been confined to using, among others, temporal integration techniques as ways of investigating visual persistence. The basic principle of integration methods is that the maximum limit of the temporal gap between the successive stimuli, whereby a combined percept can still be perceived, defines the persistence duration. This approach may be somewhat unfortunate. It is based on the intuitive belief that integration relies on the passive summation of visual information across time. The possibility that the processes which underlie integration may rely on more complex principles has rarely been considered in great depth. A class of hypotheses, known as

perceptual moment theory, is one of the exceptions. However, as will be shown, the only viable version of this theory is severely limited in its explanatory potential.

The present state of affairs in this area of research is not altogether surprising. The idea of visual persistence has been in existence for millennia (Allen, 1926 attributes a reference to Aristotle [384-322 B.C.E.]), but perceptual integration phenomena could not be adequately studied until the invention of the tachistoscope early this century (e.g. Wertheimer, 1912). It may be that the fact that a conceptual framework for the understanding of persistence was already in place meant that it was all too easy to fit integration into the existing paradigm.

The empirical work in this thesis represents an attempt to redress the balance of interest in temporal integration phenomena, although the prominent role of persistence is still emphasized. Hence, the present chapter reflects the traditional subsumption of the study of integration to visual persistence. Numbered sections discuss certain various aspects of persistence and, where appropriate, how these relate to temporal integration. Separate sections highlight the empirical findings from general persistence investigations and attempt to relate these to theoretical issues.

1.2 Temporal Acuity: Basic Theoretical Approaches

The normal human visual perception system generally has excellent spatial resolving power. Although it is not the best to be found in the animal kingdom (a hawk's vi-

sion has something like five times a human's spatial resolution), a person with unexceptional 20/20 vision can visually differentiate two parallel lines separated by a gap of one minute of arc, from a distance of twenty feet.

The temporal resolving powers of the human visual system are another matter, however. If, for example, two very brief flashes of light are presented in succession and separated by an interval of, say, 20 milliseconds (ms), then it will appear to an observer that both of them occurred simultaneously. Allport (1970) showed that when a moving object is illuminated stroboscopically at about 10 flashes per second a number of replicas of the object, spread out in space, will be seen. If a stroboscope is flashed at a light adapted subject, then at frequencies above 50 flashes per second the sensation of flicker will disappear, to be replaced by an apparently steady light source. The threshold at which flicker just begins to be perceived is called the critical fusion frequency (cff). The cff is variable in that it decreases as flash luminance increases.

In everyday life, technology exploits this lack of temporal acuity. For instance, the picture on an ordinary British television set is only replaced (i.e. refreshed) every 20 ms. In some countries the refresh rate is even slower, yet flicker is not ordinarily perceived. If, however, a pencil is placed in a line between the eyes and the TV screen and waved in a fanlike motion, backwards and forwards, then the stroboscopic nature of the light becomes apparent, as a number of discrete images of the pencil are seen.

In backward and forward masking by light, a brief duration visual stimulus, say, a disk or a bar, may be masked (i.e. rendered less discernible) by a previous (forward masking) or following (backward masking) flash of light, when presented over the same spatial location as the target stimulus. This type of masking has been shown to be strongest when stimulus-onset-asynchrony[1] (SOA) is 0 ms (i.e. when both stimulus and mask commence simultaneously), and to decline as SOA becomes positive or negative. Some investigators have suggested that forward and backward masking effects are temporally symmetrical (Eriksen and Hoffman, 1963; Eriksen and Lappin, 1964; Mowbray and Durr, 1964). Eriksen (1966) argued that these masking effects were due to luminance summation. He proposed that if a brief duration visual target is preceded or followed by a uniformly illuminated field, then if the SOA is short enough the luminances of both target and masking fields will summate. This would lead to an apparent reduction in contrast between a target and its background field, subsequently causing a reduction in ability to discriminate between the two.

Temporal summation effects can also be observed when unitary visual stimuli are considered. If the perceptual thresholds of (target) light pulses of various but short durations are empirically determined (i.e. by varying luminance to the point where the stimulus has a 50% probability of being perceived), the relationship between luminance and time is found to be reciprocal. This means

[1]The period between 1st stimulus onset and 2nd stimulus onset.

that the threshold visibility of equal energy stimuli will remain constant regardless of their absolute intensities or durations. This effect, known as Bloch's Law, may be expressed by the formula E=IxT, where E is stimulus energy and I and T are stimulus intensity and stimulus duration respectively. This reciprocity holds true for constant background luminances up to a critical target duration which is generally considered to be about 100 ms. A graphical representation of threshold values, where log luminance and log duration are plotted, would give rise to a slope of -1.0. Beyond the critical duration, this relationship begins to break down and luminance becomes more important than duration. Servière *et al* (1977a) showed that this relationship also appears to hold true for suprathreshold stimuli. They achieved their measures by equating the apparent brightness of stimuli of different intensities and durations with various constant reference stimuli.

The intuitive explanation, that visual persistence can explain all the above described effects, seems at first glance to be a perfectly reasonable one. For example, say a visual stimulus presented for a 10 ms duration has a sensory persistence of 100 ms from stimulus offset. If a similar following stimulus arrives within the persistence period of the first one, then the two stimulus representations could overlap in time, and might well appear to become phenomenally integrated. A following stimulus arriving at an SOA of 30 ms, for instance, would result in the sensory registrations of both stimuli coexisting for a period of 80 ms. If the following

stimulus was presented to a spatial location adjacent to the first, then the two stimuli might be seen at the same time. Such a *temporal integration* effect might be expected from the examples given above and indeed, as will be discussed below, it is not hard to obtain empirically.

This explanation of temporal integration in terms of visual persistence is highly oversimplified. For one thing, the possibility of multiple forms of persistence (see below) confuses the issue. It does seem, however, that many researchers of temporal integration effects have been influenced by this intuitively satisfying sensory overlay hypothesis, which is referred to here as *passive integration.*

Psychological Moment Theories

Stroud (1956) provided an alternative paradigm for the above described effects, by suggesting the possibility that perceptual information is sampled in discrete "chunks", over a time period of approximately 100 ms. Within each chunk perceptual information would become summated so that sequential data would be treated as unitary, i.e. stimulus presentation order could not be discriminated. It also neatly explains temporal summation, since any events occurring within a "moment" would be smeared across time, giving rise to the observed averaging of energy. Each moment was hypothesized to be non-overlapping and discrete. An internal clock might regulate this process; Kristofferson (1967) suggested that the alpha rhythm, operating at 10 Hz., might be a

good candidate. In fact, a discrete moment hypothesis, as this formulation has been called, needs neither to be central nor continuous. A frame (i.e. moment) could be conceived to be packaged peripherally and triggered by a stimulus event. As Haber (1973) points out, the latter concept would be useful in helping to explain why the hypothesized perceptual moments appear to decrease with increases in luminance. If the hypothesized moment were able to be regulated peripherally, then the visual system might be able to optimize its performance under various prevailing lighting conditions. For instance, in low luminance conditions the priority would be to collect light "... doing so at the expense of optimal resolution in time and space" (Haber, 1973).

The travelling moment hypothesis, first proposed by James (1890), counts as an alternative to the discrete moment. Consecutive moments with this hypothesis are neither discrete nor nonoverlapping. Instead, perceptual events might be continuously integrated across a certain span of time. The duration of the span might be of the order of 100 ms, which would conveniently compare with cff and the critical duration for Bloch's law. Allport (1968) attempts to aid conceptualization with the following illustration:

> "To a man standing on the platform, the occupants of a passing train are revealed compartment by compartment as each window draws by....To an observer in one of the compartments, on the other hand, the field of view is always bounded by his carriage window. New elements of the passing scene enter his view continuously from one side of the window, while others drop out of it at the other. Given a temporal rather than a spatial extension, the moving window analogy corresponds to the idea of a continuous 'travelling moment'".

Allport (1968) tested the predictions of both the discrete and travelling moment hypotheses and found no evidence for the former. In one elegant experiment twelve bars were drawn sequentially on a cathode ray tube (CRT). The process was cyclic and bars consecutive in the sequence were either drawn above or below the previous one, depending on the trial condition. At very high cycle frequencies a stack of 12 horizontal bars were seen on the CRT. The cycle frequency was then reduced until only eleven bars could be viewed at any moment.

The prediction of the discrete moment hypothesis was that eleven bars would be seen with a shadow, representing the missing bar, moving in the opposite direction to the one in which the bars were being stacked. Imagine the bars are being stacked towards the top of the screen of the CRT. If the bottom-most bar were labelled *j*, and one moment encompasses 11 bars, then, on the first cycle, the shadow would replace the *j+11*th bar. In the following moment *j+11* would be included along with bars *j* to *j+9* and the shadow would fall on *j+10*. Repeating this process, it can be seen that the shadow would always move downwards as the bars are stacked upwards. Clearly the shadow's movement would reverse direction if the bars were stacked downwards.

The travelling moment hypothesis, on the other hand, would predict that the shadow should move in the same direction as the stacking. At the start of the cycle, bars *j* to *j+10* would be captured by the travelling moment and the shadow would replace bar *j+11*. As the moment

travelled, *J+11* would be included but *j* would be excluded. In a further instant, *j* would be included leaving *j+1* to be excluded, and so on. Thus whichever direction the bars were stacked in, the shadow should have moved the same way. The predictions of both hypotheses are depicted in Figure 1.1. In the event, Allport showed that the latter prediction was always true.

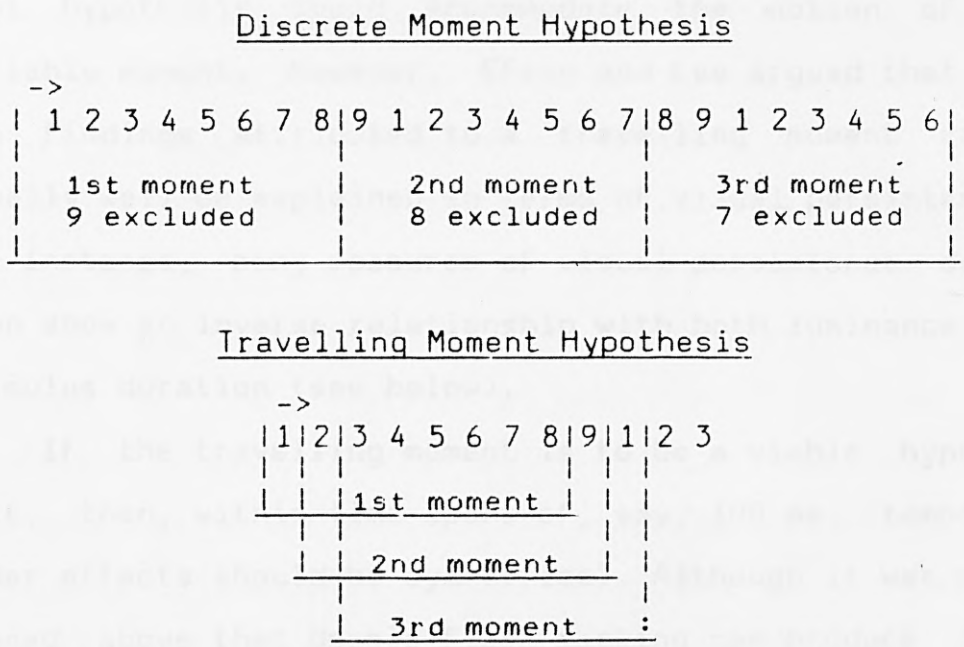


Figure 1.1: Predictions of Discrete versus Travelling Moment Hypotheses. 9 elements are depicted instead of the 12 used by Allport. Hence, for the sake of illustration, the moment is shown to span only 8 elements. See text for further explanation. (Based on Allport 1968)

Both Allport (1970) and Efron and Lee (1971), measured the moment with the aid of a rotating disk with one, clearly visible, radial line attached to it. The setup was illuminated by a stroboscope. When the rotation speed and stroboscopic frequency were adjusted, a number of radial lines could be seen. By counting the number of ra-

dial lines seen, a value for the duration of the moment could be obtained. Both investigations showed that the duration of the moment reduced as illumination increased. Efron and Lee, for instance, derived a mean moment of approximately 140 ms, where disk illumination was 1.2 foot Lamberts (fL) but when disk illumination was decreased by 1.5 log units, the apparent moment increased by a mean of approximately 26 ms. As discussed above, a perceptual moment hypothesis could accommodate the notion of a variable moment. However, Efron and Lee argued that all the findings attributed to a travelling moment could equally well be explained in terms of visual persistence. For instance, many measures of visual persistence duration show an inverse relationship with both luminance and stimulus duration (see below).

If the travelling moment is to be a viable hypothesis, then, within time spans of, say, 100 ms, temporal order effects should be symmetrical. Although it was mentioned above that double flash masking can produce symmetrical functions, there are a number of investigators who report otherwise and have found forward masking to be more enduring (Braddick, 1973; Coenen and Eijkman, 1972; Schiller and Smith, 1965; Smith and Schiller, 1966; Sperling, 1965). Metacontrast and paracontrast masking (backward and forward masking with nonoverlapping target and mask contours; see page 29) show asymmetrical effects, the former being much stronger. Furthermore, maximal masking effects are not found at 0 ms SOA (Averbach and Coriell, 1961; Breitmeyer and Ganz, 1976).

The reciprocal relationship between intensity and

duration for a visual stimulus shorter than the critical duration of approximately 100 ms (Bloch's law), was discussed above. Breitmeyer (1984) points out that a 50 ms flash presented at intensity *I* should, if the distribution of energy within the critical duration were irrelevant, elicit the same response as two 25 ms flashes presented at intensity *I*. This relationship would be expected to hold true as long as total stimulus duration did not exceed the critical duration. Subthreshold investigations into double flash summation do not confirm this prediction (Ikeda, 1965; Rashbass, 1970).

Ikeda (1965, 1986) showed that where background intensity was 61.2 Trolands[1] (Td), and the duration of either of the flashes was 12.5 ms, then full summation occurred at flash intervals of less than 20 ms. As the separation between flashes increased, so summation decreased until it was nonexistent where SOA was 40 ms. Beyond this point (when SOA was 40 to 80 ms), negative summation was found. In other words, there was some evidence of an inhibitory interaction between the double flashes. Where the background intensity was higher (328 Td), then the 20 ms critical duration remained but partial summation was extended up to 60 ms. Clearly, an explanation of the changes in critical duration for temporal summation in terms of a travelling moment would ignore the complexities of the double flash interactions.

The evidence from masking and temporal summation studies as presented above is intended to show that

[1]Measure of retinal illumination: This is given by the product of stimulus luminance (candelas per square metre) and pupil area (in square millimetres).

psychological moment theories are not particularly useful for an understanding of these and related phenomena:

> "...visible persistence is of much greater heuristic value in explaining psychological indices of not only masking but also form integration than is the psychological moment hypothesis." (Breitmeyer, 1984).

It will be noted that temporal form integration, which might be considered to be a special case of temporal integration, has not been considered in this critique of the psychological moment theory. Empirical work in that field does, undoubtedly, militate against moment theories. Since the bulk of the interest of this thesis is, in fact, concerned with temporal form integration, the subject will be considered in greater depth later in this chapter.

1.3 Partial Report

As discussed earlier, the concept of visual persistence is hardly a new idea. However, modern interest in the subject was regenerated by Sperling (1960) when he reported his work on the partial report superiority effect. As will be seen, his results seemed to implicate the existence of a high capacity photograph-like store of visual information. This visual store was held to be generated at stimulus offset and seemed to decay rapidly over a period of several hundred milliseconds.

In his first experiments, he extended the work of Wundt (1899) to show that the number of items that could be reported from a brief central presentation of a random array of letters and numbers was very limited (4 to 5 items). He found that this number remained more or less

constant, regardless of how many items were in the array (he tested up to 12 items) and regardless of array format. Furthermore, even when the exposure duration was varied between 15 and 500 ms, the average number of items that could be reported remained constant. Sperling followed the lead of Miller (1956), by referring to the number of items reported in this way as "the span of immediate attention". The type of experimental design described above is generally termed *full report*.

His later experiments were changed into a design that was to become known as the *partial report* technique. Subjects were presented with a 3x3 or 4x4 random letter array. In this case, subjects (S's) were required to report only one row from the array. They were informed as to which row to report by an auditory tone (the probe); high, medium and low tones indicated the top, middle or bottom row respectively. A further consideration in the design was that the probe was delayed across six levels between -100 ms (i.e. the probe was presented 100 ms before array onset) and five positive delays up to 1 sec (measured from array offset).

The results showed that whilst report performance was virtually 100% at the negative probe delay, it rapidly declined as the probe delay became positive and increased. However, mean performance at the 500 ms probe delay was still superior to the 1 sec delay. Since S's could not have known in advance which row was going to be cued, it followed that they were able to retain more information about arrays than they could report. The fact that the partial report advantage declined rapidly as

probe delay increased indicated that this information was subject to decay. By multiplying the percentage of letters correctly reported by the number of items in the total array, divided by 100, a figure for the number of items perceptually available from the total array, under partial report conditions, could be calculated. A comparison between the span of immediate memory (i.e. the mean number of items retrieved in the full report mode) and partial report performance, showed that the latter was superior at all probe delays up to and including 500 ms. This effect is now generally referred to as 'partial report superiority'. Sperling therefore concluded three things from his research:

> "...a large amount of information becomes available to observers of a brief visual presentation, this information decays rapidly, the final level is approximately equal to the span of immediate memory. Although the exact, quantitative aspects of information that become available following a brief exposure unquestionably depend upon the precise conditions of presentation..." (Sperling, 1960).

The latter assertion was concluded from the finding that partial report performance could be influenced according to whether the post-exposure field was bright or dark, the former giving rise to poorer performance.

Averbach and Coriell (1961) developed an alternative form of the partial report procedure where a visual bar marker was used to indicate a single letter target. The target was one of 16 letters presented in a 2x8 array, for a duration of 50 ms. Although a full report condition was not included in their experiments, increases in probe delay did lead to deteriorations in performance. Scores became asymptotic at between 25% and 35% correct re-

sponses, where delays, as measured by SOA, were of the order of 200 ms. They pointed out, however, that whilst these results were conducive to the concept of the time decay of a short term visual storage mechanism, they did not reflect the true decay rate, for two reasons. Firstly, they would have expected performance to decline to chance level at long enough probe delays. The fact that the asymptote was well above this figure suggested the involvement of more permanent memory mechanisms. Secondly, "...because the process of detecting a marker [i.e. probe] and reading a letter undoubtedly takes time, the measured performance suggests a storage time that is shorter than the true storage time." (Averbach and Coriell, 1961).

In further experiments, Averbach and Coriell investigated the effects of two other types of visual probe. One probe was a circle filled with a grid. In this case, performance was at its worst where the probe coincided with the offset of the array but improved steadily with further increases of SOA. They interpreted the latter results by positing that the contours of the letter and probe had merged in short term visual memory, by a process of temporal summation. This had degraded the quality of the visual image of the letter before it could be decoded and identified. However, as SOA increased, so more time would be allowed for letter processing and hence the improvement in performance.

An alternative probe was in the form of a circle that surrounded one of the letters. Surprisingly, even though the contours of the target and probe did not

physically overlap, the locus of performance against probe delay was a *U* shaped curve with the trough occurring when SOA was 100 ms. It appeared that the target was masked by the probe but, unlike the other backward masking effect that was discussed earlier, maximum masking here was obtained when the two stimuli were projected asynchronously.

The effects of this circle-only probe were something of a surprise at the time. Averbach and Coriell interpreted the good performance, at very short SOA's, in terms of temporal integration. Thus the letter was clearly seen surrounded by the circle probe by means of, as they understood it, a special case of temporal summation. However, as SOA increased to 100 ms, the summation effect turned into an erasure effect that effectively blanked out the contours of the target before it could be identified. Further increases in SOA were held to provide more time for target processing and hence the *U* shaped performance curve. The erasure effect with close but non-overlapping contours has since become known as metacontrast masking. The forward masking corollary to this is known as paracontrast.

The collective findings of both Sperling and Averbach and Coriell seemed to reflect the same type of short term visual store. This was described by Sperling (1960), as follows:

> "...the evidence...is consistent with the hypothesis that [visual] information is initially stored as a visual image and that S's can effectively utilize this information in their partial reports. In the present context, the term, visual image, is taken to mean that (a) the observer behaves as though the physical stimulus were still

> present when it is not (that is after it has been removed) and that (b) his behavior in the absence of the stimulus remains a function of the same variables of visual stimulation as it is in its presence."

The fact that the information held in the hypothesized visual store could be masked by a following visual stimulus, indicated that it was *visually*, rather than *semantically*, coded. That the contents of this visual store were subject to rapid decay was indicated by the decline of partial report superiority over full report as probe delay increased.

This hypothesized short term visual store was later dubbed *iconic memory* by Neisser (1967) and was understood to be coded in a precategorical format. That is to say, it was supposed that it acted as a kind of visual template whose persistence allowed for the necessary processing time required to transform the iconic or pictorial data into codes that could be stored in more durable memory. Thus, the action of a short delay probe enabled observers to selectively direct attention to the relevant portions of the icon so that the required items could become categorically coded and verbally identified.

The precategorical nature of iconic memory was inferred from findings that partial report superiority could only be obtained with probes that directed selection of visual properties of an array; these included spatial position, colour, size and shape (Banks and Barber, 1977; Clarke, 1969; Turvey and Kravetz, 1970; Von Wright, 1968a,b). Where selection was on the basis of whether an item was a letter or a digit then partial report performance was no better than full report

(Sperling, 1960; Von Wright, 1968a,b). Coltheart (1972) explains these differential effects as follows:

> "...the subject cannot selectively process items in iconic memory according to whether they are letters or digits. This is because he cannot tell whether an item is a letter or digit until it is processed, and so whether an item is a letter or a digit cannot determine whether it will be processed or not. On the other hand, simple physical characteristics such as the spatial position, size, shape or colour of an item can be discriminated without the item having been identified, and so whether an item will be identified can be controlled by the physical characteristics it possesses".

The problem of the full report limitation is not of direct relevance to the subject matter of this thesis. However, it has been hypothesized that the partial-full report differential represents a bottleneck for the transfer of items from iconic memory to the more durable postcategorical memory stage (see Coltheart 1972). In the view of some more recent researchers, however, (e.g. Di Lollo, 1978; Irwin and Yeomans, 1986; Mewhort *et al*, 1981), many more items than can be reported in full report may be coded categorically. One hypothesis to be considered later in this chapter is the possibility that certain qualities of information (such as spatial qualities) may be lost in the transfer from iconic memory to more durable memory.

1.4 Multiple Forms of Visual Persistence

The concept of *iconic memory* (Neisser, 1967), as exemplified by partial report, served as a template for further research even though these new methods used a variety of different techniques. Coltheart (1980a, 1980b) has listed seven alternative techniques, besides partial

report, whereby visual persistence has been investigated. Within and between these techniques findings are variable and often contradictory. Some investigators of persistence duration have found an inverse relationship with both brightness and test stimulus duration. Others have found the exact opposite, even when employing apparently similar techniques. Measures of the duration of persistence also seem to vary; some investigations show a time course of about 130 ms, whilst others estimate closer to half a second.

A problem of particular interest in visual persistence research is the question of whether this phenomenon is generated by the cortex (and therefore may be said to have a central locus), or by more peripheral processes that might be centred in the retina or in neural pathways below the level of the cortex (both these loci may be called peripheral). Answers to this question must rely on hypothetical inferences, rather than direct observation, since an instrument that can observe neural functioning in sufficient detail to resolve this question has yet to be invented. Opinion tends to fall into three categories. Firstly, as will be seen below, there are those investigators who propose that there are different forms of visual persistence (not including afterimages), so that it would be reasonable to obtain both central and peripheral indications. Others appear to believe that there is only one manifest form of persistence and that it is generated peripherally. Lastly (but by no means least importantly), there are those who appear to believe that persistence is mainly located in central mechanisms.

There are persistence-like phenomena known as strong

and weak afterimages that almost certainly have a retinal locus. These will be considered briefly below but, for reasons that will become clear, they do not properly belong to the class of phenomena being discussed in this thesis.

One of the most influential recent papers on the subject of persistence was produced by Coltheart (1980a). He argued that most techniques for measuring visual persistence duration showed an inverse relationship between that and stimulus parameters such as brightness and duration. He suggested that this relationship held true as long as retinal illumination was less than 1000 td. Partial report (PR) experimentation, on the other hand, shows either no effect of stimulus duration or a positive effect, even though luminance parameters are usually less than 1000 td. It therefore seemed to him that the persistence evinced by PR was qualitatively different to that demonstrated via other techniques. He proposed that persistence could exist in any of three ways:

> "There are...three distinct senses in which a visual stimulus may be said to persist after its physical offset: the stimulus may continue to be experienced (visible persistence); the responses of stages of the visual system may go on occurring (neural persistence); and the visual information contained in the stimulus may continue to be available (iconic memory)." Coltheart (1980b).

Visible persistence, he concluded, might well be the result of ongoing neural processes (i.e. neural persistence) but not of *iconic memory*, or of *information persistence*, which was what he termed the hypothetical manifestation of iconic processes. All the available techniques for studying persistence, except for PR, were

direct methods of approach, which emphasized the role of visible persistence. Partial report, the only indirect method, did not access visible persistence, but only information persistence. Coltheart thought that information persistence would be generated centrally (this has generally always been the main belief for persistence manifest via PR) but he has reserved judgement about visible persistence.

There was another reason to doubt that cue (i.e. probe) delay effects (in PR) were simply caused by rapidly decaying information within a visible icon. A number of studies have shown that when partial report errors were separated into intrusion errors (i.e. reporting an item that was not present in the array) and location errors (i.e. reporting an item that was present in the array but locating it incorrectly), the latter errors predominate and increase at a much faster rate as probe delay is lengthened (Di Lollo, 1978; Eriksen and Rohrbaugh, 1970; Irwin and Yeomans, 1986; Mewhort *et al* 1981, 1984; Townsend, 1973; Yeomans and Irwin, 1985). If the hypothesized iconic trace is conceptualized as a fast decaying photograph-like store of visual data then it is difficult to see why there should be differential rates of information loss. General and progressive degradation of the icon should lead to an increasing tendency towards item misidentification and location errors ought to reflect this misidentification process. The relative frequency of intrusion and location errors might be expected to be responsive to the ratio of the number of letters in a PR array to the number of characters in the full set that a subject can choose from.

The fact that this is not so has led to several new hypotheses regarding the nature of iconic memory. However, all of these hypotheses share the assumption, derived from the common observation that mislocation errors exceed intrusion errors in PR, that spatial information is less robust than identity information. These hypotheses will be considered in greater depth later on in this chapter.

Afterimages

Long (1980) has energetically criticized Coltheart's appraisal of visual persistence research. The position that he and his co-researchers take is that most of the findings which highlight the existence of visual persistence are, in reality, merely forms of afterimages.

The term *afterimage* applies to that class of visual persistences which can be attributed to residual activity in the light sensitive cells (rods and cones) in the retina. The dark spots in the visual field caused by looking for too long at a very bright object (e.g. the sun), are negative afterimages. The fundamental afterimage is, in fact, positive but due to restimulation of the retina, a negative image is seen (Padgham, 1965).

Sakitt (1976a) distinguished between three forms of visual persistences, all of which, she believed, were types of afterimages. Much of her data were easily explainable in terms of the strong afterimages predicted by the photochemical kinetic theory (Alpern and Barr, 1962). They increased in duration with increases in luminance

but were only expected to be induced by stimuli above 6300 td. However, there was evidence of much shorter duration afterimages (from 250 ms to several seconds) that also evidenced a positive relationship with luminance. Sakitt called these "weak" afterimages and noted that the positive relationship between duration and luminance began at stimulus luminances of about 1000 td. She further noted that this luminance value coincided with the point where rhodopsin in the photosensitive cells begins to become significantly bleached. Her conclusions were, however, that, unlike the strong afterimages, "...the weak afterimage is of receptor origin but not due to simple photoproduct kinetics".

Below stimulus luminances of 1000 td there was still evidence of persistence, which lasted between 50 ms and 200 ms. The *ultraweak* afterimages, as Sakitt termed these very short persistences, were apparently independent of stimulus intensity. However, she did admit that her experimental apparatus might have been relatively insensitive to fine variations in persistence durations. Although the weak and ultraweak afterimages were clearly distinguishable by the effects of stimulus intensity parameters, she held that they were both explainable in terms of similar photoreceptor mechanisms.

As mentioned above, Sakitt, Long and their co-workers have generalized their work on afterimages to include most manifestations of visual persistence (see for example Long, 1980; Long and Sakitt; 1980a, b; Sakitt, 1976a, b). They hold that this category includes the persistence implied by iconic memory in partial report, as

well as persistence highlighted by the direct techniques. Long and Sakitt (1980a) predict the effects of stimulus luminance and duration parameters on visual persistence, as follows:

> "...a retinal interpretation of iconic memory would predict a strongly positive energy-dependent nature to ...[visual] persistence. As either target luminance or target duration increases (at least up to some limiting value), the duration of the icon should also increase due to prolonged retinal activity. Given the luminance-duration reciprocity observed in retinal processes up to some critical duration...,the effects of increasing either luminance or duration on iconic persistence should be identical."

Long and his colleagues have, in fact, produced a wealth of evidence in support of this afterimage hypothesis (i.e. positive target luminance and duration effects). Their experimental designs have incorporated a number of methods ranging from partial report, to temporal integration, to judgements of synchrony (e.g. Long 1979a, b, 1982, 1985a; Long and Beaton, 1982; Long and McCarthy, 1982; Long and Sakitt, 1980a, b; Sakitt, 1976a, b). Not all of these studies have produced unequivocal evidence, however, but a critique is reserved for the methodology section (see below).

On the other hand , as mentioned above (and discussed further below), there is much evidence to show that at stimulus luminances below 1000 td, persistence duration is inversely related to both target luminance and target duration (partial report excepting). It is difficult to see how these findings can be related to Sakitt's model of the ultraweak afterimage. Nevertheless, Sakitt and Long currently remain adamant regarding their afterimage hypothesis and some of the arguments that they

propose to support it are considered in the following sections.

Type I and Type II persistence

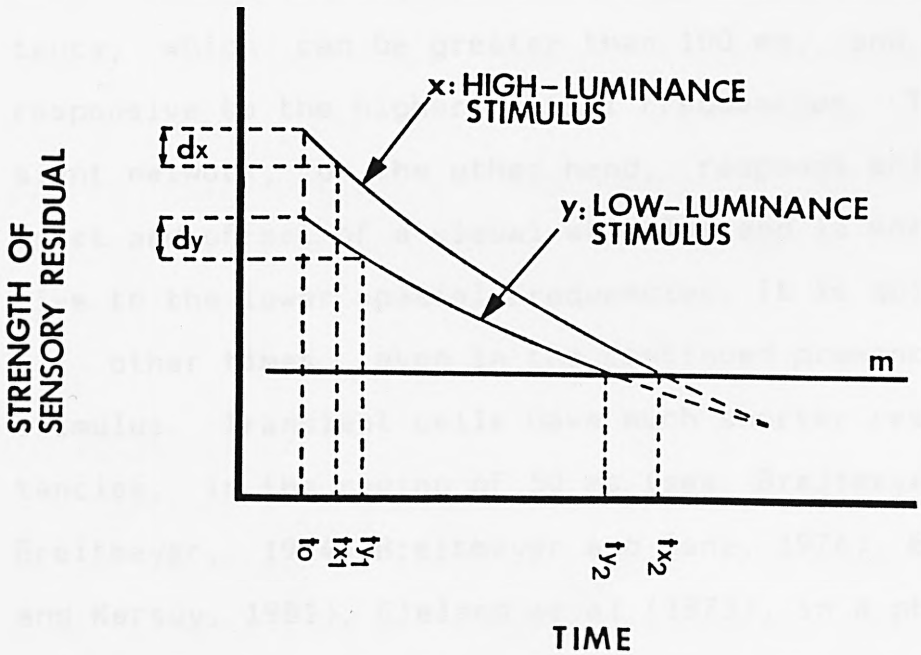
Hawkins and Shulman (1979) suggested an idea which, on initial consideration, promised to resolve the conflict between direct and inverse relationships in visual persistence phenomena. They pointed out that functions of persistence may vary, depending on the salient aspects of task requirements. According to them, if the perception of the offset of a visual stimulus is accessed then inverse relationships with target luminance would be found. Conversely, if the subject is required to attend to, or make use of, the full time course of persistence, then positive relationships should prevail. These two different aspects of visual persistence were respectively termed Type I and Type II persistence.

Hawkins and Shulman (1979) have based their arguments on three assumptions:

> "...(1) The strength of the sensory residual of an abruptly terminated visual stimulus is assumed to decay as a negatively accelerated function of time...(2) the initial strength of the residual varies with stimulus intensity; and (3) the rate parameter of the persistence function does not decline with increases in intensity. This third assumption implies that the time required for the function to decay by any fixed amount will vary as the inverse of the initial value of the function".

The relevant persistence curves are shown in Figure 1.2. Type I persistence duration is defined by the time taken for a just noticeable drop in target luminance to be perceived. In Figure 1.2, this drop is given by dx and dy where $dx=dy$, but the rate of decay of the sensory residual, at equivalent latencies after stimulus offset, is

greater for the high luminance stimulus. It can be seen that the time needed to perceive the drop in the sensory residual from the high luminance stimulus (dx) is tx_1, whilst to see an equivalent drop for the low luminance sensory residual (dy) is ty_1. Thus tx_1 occurs sooner than ty_1. Conversely, Type II persistence focuses on the extent over time that information, within the sensory residual, remains available. The horizontal line, labelled m in Figure 1.2, represents the threshold below which information, held by the residual, becomes unavailable. Clearly, therefore, the useful duration of the residual of the high luminance stimulus (i.e. time tx_2) is longer than that of the residual of the lower luminance stimulus (i.e. time ty_2).



m = threshold level of visibility of the sensory residual.
Type I persistence is given at times tx_1 and ty_1.
Type II persistence is given at times tx_2 and ty_2.

Figure 1.2: Hypothesized effects of Stimulus Luminance on Type I and Type II Visual Persistence. See text for explanation. (After Hawkins and Shulman, 1979).

Hawkins and Shulman speculated that the conditions where Type I or Type II functions might be found would depend on the experimental procedures and also, in some cases, on the instructions given to subjects. As will be seen when direct methods are discussed in more detail, there is some evidence to support this notion. However, it will also become clear that the bulk of results cannot adequately be explained in this way.

Neurological considerations: Transient and sustained channels

Two neural networks have been identified in the mediation of visual perception. One network consists of sustained cells which respond continuously in the presence of a visual stimulus. This network has a long latency, which can be greater than 100 ms, and is more responsive to the higher spatial frequencies. The transient network, on the other hand, responds only to the onset and offset of a visual stimulus and is more sensitive to the lower spatial frequencies. It is quiescent at all other times, even in the continued presence of the stimulus. Transient cells have much shorter response latencies, in the region of 50 ms (see Breitmeyer, 1980; Breitmeyer, 1984; Breitmeyer and Ganz, 1976; Breitmeyer and Kersey, 1981). Cleland *et al* (1973), in a physiological study, showed that sustained neurones responded longer and with longer latencies to a 2 ms light flash than transient neurones.

As will be seen in the section where direct methods of investigation are considered, there is evidence that

networks of sustained cells may be involved in persistence. Furthermore, certain reciprocal inhibitory characteristics have been found which may operate both between and within these neural networks.

Singer and Phillips (1974) have accessed the neurophysiological activities of two different types of transient cell. Moreover, Phillips and Singer (1974) were able to demonstrate their operations in psychophysical studies. One of these gives a transient response to the onset of a visual stimulus whilst the other type responds to offset. The interactions of these neurones and their possible application to persistence research will be considered in more depth in Chapter 5.

The importance of offset and onset detection to temporal integration constitutes a recurrent theme in this thesis. Whether or not transient neural networks are directly responsible for some of the findings to be reported will remain an open question. However, this possibility is dealt with in the final discussion (Chapter 5).

1.5 Terminology

Because of the recent controversies over the hypothesized multiple persistences, the terminology that is used in this area of research has become somewhat confused. In the earlier days of partial report investigations, when persistence was understood to be evidence of a unitary short-term visual store, it was often reasonable to describe persistence in terms of the hypothetical processes that were thought to underlie it. Thus, when

writers used the term *iconic memory* the reader would generally understand this to be a fast fading photograph-like representation that was probably visible.

Currently, however, it is important to distinguish between investigatory procedure and hypothetical process. Unfortunately, this is not often done. It is common practice to talk about *information persistence* when discussing the results of partial report studies and *visible persistence* when the findings from direct studies are being considered. To further complicate matters other authors, who do not subscribe to any clear distinction between forms of persistence, have sometimes used the term *iconic memory* as a generic reference to persistence. Others who do appear to follow Coltheart's classification only use this term when they are referring specifically to the concept of *information persistence*.

Later chapters question whether the type of persistence that is manifest by some direct methods is, in fact, qualitatively different from that which is found via indirect methods. Therefore, in this thesis, persistence phenomena are not distinguished on a procedural basis. Instead, the term *visual persistence* will generally be employed when some form of persistence is evidenced but no specific process or mechanism is necessarily implied. The other labels that were mentioned above will be reserved to indicate hypothetical processes or phenomenological experience.

Di Lollo (1984) has pointed out that the terms *Type I* and *Type II* persistences are somewhat unfortunate. They could be mistakenly applied to the concept of separate

types of persistences, instead of to different aspects of a unitary form of persistence, as originally intended by Hawkins and Shulman (1979). Considerable confusion seems to have been caused by some authors who have categorized the Hawkins and Shulman's persistence Types on the basis of empirical evidence rather than experimental procedures. Bowling and Lovegrove (1982), for instance, clearly imply that certain persistence of form and temporal integration studies were Type I measurements. These studies have indeed given rise to Type I data but the experimental paradigms, on the face of it, required the use of Type II information. These considerations are explored in the following section where Hawkins and Shulman's original meanings are adhered to.

1.6 Direct Techniques: Review and Critical Evaluation

This section reviews some of the various techniques that have commonly been used in order to study visual persistence (see also Coltheart, 1980a; Long, 1980). Not all of the techniques mentioned may be of direct relevance to the empirical content of this thesis, and this is partially reflected in the amount of space given to each of them. However, as has been discussed, there is currently some controversy regarding the possibility of multiple forms of persistence, much of this stemming from differing findings by differing techniques. An overview of these various experimental methods might therefore be useful for an understanding of the divergent opinions held by current researchers. Although, as mentioned above, Coltheart's classification for *direct* methods (as

opposed to the *indirect* partial report techniques) has been adhered to, it will be examined critically in due course.

Most of the visual persistences manifest by direct methods have been usually linked, sometimes only implicitly, with the concept of *visible* persistence. As an explanation it has a satisfying intuitive feel but, as will be seen, there are grounds for questioning whether this belief is entirely appropriate. The reasons for challenging this dogma will become clear in the ensuing empirical chapters.

The presentation format here is slightly different to the other sections in this chapter. Each technique is considered under its own heading and the writer's comments are appended to each of these subsections.

Judgement of synchrony.

This technique was developed by Sperling (1967) and has since been extensively employed by other researchers (e.g. Bowen *et al* 1974; Efron 1970 a, b; Haber and Standing, 1970; Long and Gildea, 1981; Long and McCarthy, 1982; Sakitt, 1976). Its purpose was to measure the perceived duration of a visual stimulus. Results indicated an inverse relationship between stimulus duration and persistence duration, up to a critical duration of the former.

Efron (1970b), for instance, presented a brief test stimulus followed by a probe stimulus, which was an auditory click. The test stimulus was a homogenous disk subtending a visual angle of 1.66°. It was presented

foveally at a luminance of 3.4 fL. In one condition, the subject was required to synchronise the onset of the probe with the moment of onset of the test stimulus. In another S synchronised the onset of the probe with the offset of the test stimulus. By subtracting the onset error from the offset error, a figure for the perceptual persistence of the target stimulus was found. Persistence decreased from about 120 ms, where the test stimulus duration was 10 ms, to zero for test stimuli of 150 ms to 500 ms. Thus for test stimulus durations of less than 150 ms, the relationship with persistence duration gave rise to a slope of -1.00, whereas from 150 ms to 500 ms, the slope was zero. The sum of the test stimulus duration and the final error calculation, produced a figure for the phenomenal duration of the stimulus. This remained fairly constant for test stimulus durations of less than 130 ms and showed that its phenomenal duration was at least 130 ms. Similar results were found when the test stimulus was an auditory tone. This experimental paradigm was a repeat of Efron (1970a, b) and produced similar evidence. Coltheart (1980a) notes, however, that where the test probe was visual (Efron 1970a), then 100 ms was added to all persistences, even beyond test stimulus durations of 130 ms. The persistence slope, on the other hand, remained the same, regardless of probe modality.

Haber and Standing (1970) studied combinations of light and dark pre- and post-adapting fields on persistence durations of a 3 x 3 array of black letters on a light background. Using an auditory click probe stimulus on test stimulus durations of up to 1000 ms, their re-

sults accorded reasonably well with Efron's, when the pre- and post-adapting fields were dark. Other combinations gave rise to reduced persistence.

Bowen *et al* (1974) found that persistence measured by this method was also inversely related to the luminance of the test stimulus. They went on to show that where flash energy was equated by varying luminance over a range from 2.8 to 0.14 fL for stimulus durations of between 5 and 100 ms, then persistence duration was constant. As stimulus duration was further increased, then persistence declined as a function of duration.

It may be that Hawkins and Shulmans' concept of Type I and Type II persistence may be of some value in explaining the inverse relationship between stimulus energy and persistence duration. If an observer's criterion for the offset of the target stimulus was actually the moment of offset, rather than the cessation of all sensation, then this would be a Type I process and the inverse relationship would be predicted.

This is the view expressed by Long (1979) and indeed Long and McCarthy (1982) tested this idea by varying the instructions in a judgement of synchrony experiment. They found that when the instructions required S's to attend to the absolute end of all sensation of the stimulus (i.e. a Type II process), then persistence durations increased at higher luminances. When they were instructed to attend to the moment of offset (a Type I process), there was an inverse effect of luminance.

Di Lollo (1984), in opposition to this interpretation, vigorously endorses the idea that judgement of

synchrony experiments, where inverse stimulus energy-persistence duration relationships have been found, were accessing Type II processes. For example, to support this assertion he cites a personal communication from L. Matin regarding these experiments, as follows: "The intent of the instructions was to have the observer's report indicate the moment when the flash had disappeared entirely". A similar confirmation was given by Efron (1973).

Di Lollo (1984) therefore concluded:

> "On rational and empirical grounds, resolution of the inconsistency among studies of the effects of luminance on persistence seems to hinge not on whether the procedures yield Type I or Type II measures but on whether they are likely to generate retinal afterimages".

Nevertheless, Long and McCarthy (1982), as discussed above, were able to produce both Type I and Type II data, depending on instructions to subjects, and they used low luminance stimuli (5 and 15 fL), which were unlikely to have induced even weak afterimages. This finding does seem to weaken Di Lollo's argument somewhat. Moreover, it should be borne in mind that, at the time of the investigations in question, the possibility of differential effects, due to Type I and II persistences, had not been conceived. Because of this, it may be that S's criteria were not controlled as stringently as they might otherwise have been.

Comment (*Judgement of Synchrony*)

This source of persistence is clearly visible and since it is the phenomenal aspect of a stimulus that is

directly measured in judgements of synchrony, it could be said to warrant Coltheart's categorization as a "direct" method of investigation. Nevertheless, the apparent increase in persistence duration where intramodal stimuli are used (at least in the case of vision) suggests the involvement of intervening processes.

The fact that persistence duration seems to be a function of stimulus energy (Bowen *et al* (1974) up to some critical duration, would seem to justify Long and Sakitt's assertion regarding photoreceptor involvement in the persistence process. Long and McCarthy's finding that Type I and Type II functions can be obtained by varying the instructions given to subjects seems to provide further justification for this viewpoint.

As will be seen, however, Type I persistence functions are often obtained with some techniques where Type II functions would be predicted. The alternative mechanism of transient and sustained cell interactions would be altogether more complex and it is possible that this concept has more explanatory power.

Onset-offset reaction times.

The observer's task with this technique is to respond as quickly as possible, in separate trials, to the onset and offset of a visual stimulus. If it were assumed that an observer's set of criteria remained constant and also that speed of reaction at the output stage (i.e. the hypothetical latency between the moment of decision and the moment of response completion) were comparable at onset and offset, then a measure of phenomenal duration

might be obtained. In reality, these assumptions are unlikely to be perfectly realized, nevertheless rough measures of persistence might be obtained.

Pease and Sticht (1965) used long lasting visual stimuli. They presented a small visual stimulus (0.33° diameter) either to the fovea or 15° off centre. The stimulus durations were between 2 and 4 seconds and their findings were that only peripherally directed stimuli showed any evidence of persistence. Bartlet *et al* (1968) were in general agreement with Pease and Sticht but they also manipulated the wavelength of the visual stimuli. They concluded that performance was generated by the cones with foveally projected stimuli but that the rod system was involved in peripheral projections. Where short stimulus durations were employed then persistence of a monoptic letter display declined as stimulus duration increased (Briggs and Kinsbourne, 1972).

Long and McCarthy (1982) also employed the reaction time (RT) technique in one set of conditions and manipulated subject's criteria in the same way as they did with judgements of synchrony (see page 46). They again found evidence of different Type I and Type II functions.

Comment (Onset-Offset RT)

As with the judgement of synchrony task the phenomenal experience of persistence as *visible* is accessed. Again, therefore, the epithet 'direct' seems to be warranted. Bearing in mind that persistence measures obtained by this method are likely to be inaccurate, the results obtained here are not discordant with those col-

lected via synchrony judgements. Furthermore, it is interesting to note that Type I and II persistence functions may also be generated simply by varying the instructions given to observers.

Stroboscopic illumination of a moving stimulus.

This technique has already been discussed above in relation to the perceptual moment hypothesis. To recap briefly, however, if a single object, moving at around 20 cm/sec, is illuminated stroboscopically at about 10 Hz., then multiple images of that object will be seen. One hypothesis that explains this phenomenon is that the visual persistence generated by former flashes is extant during successive illuminations, thus resulting in a multiple percept. A commonly employed technique is to mount a visible radial line on a rotating disc, which is stroboscopically lit. The observer's report of the number of radii seen, together with a knowledge of the rotation speed of the disc and the stroboscope frequency, enabled the experimenter to calculate the duration of visual persistence. Allport (1970), Dixon and Hammond (1972) and Efron and Lee (1971) all found that persistence duration estimates declined with increases in the intensity of illumination. The level of stimulus intensities over these studies were all low enough not to have produced obvious retinal afterimages.

Allport (1970) employed a further measurement technique. In a second task, the subject was required to estimate the angle formed by the fan of radii seen. The counting of radii produced longer estimates of

persistence (100-300 ms) than with the latter report method (30-100 ms). Allport suggested that subjects might possibly be able to exert some control over the duration of their visual persistence. In the easier angle estimation task, a persisting visual image may not have been as necessary as in the counting task. Similarly, at the low stimulus intensity a subject might extend his persistence duration in order to compensate for the comparative paucity of visual information. A problem with this subject strategy is that a long persistence in the counting task would have been counterproductive. However, naive subjects might not have realized this. Furthermore, in support of the strategy concept Allport notes that out of fifteen subjects six of them produced no luminance effects. These six subjects also had the shortest persistence durations at low luminance intensities.

Comment (*Stroboscopic technique*)

Coltheart's categorization of the stroboscopic method as a direct way of measuring visible persistence seems premature. Although some form of visual persistence is probably implicated, it is not necessarily visible across the whole course of its existence. The observer is presented with the *fait accompli* of a final percept (i.e. multiple images). This is in contrast to the above mentioned synchrony experiments where subjects were required to attend directly to a visible image.

The general consensus of findings relating to this technique appears to support the concept of an inverse relationship between stimulus luminance and persistence

duration. This is clearly a Type I persistence function, although the method itself would presumably measure the full course of visual persistence. Hence a Type II persistence function would have been predicted according to the hypothesis proposed by Hawkins and Shulman. There seem to be at least three possible avenues towards a solution of this problem: (1) The persistence manifest by judgements of synchrony and RT techniques is a different process to that evidenced by the stroboscopic method. Persistence, with respect to the latter technique, is not always visible; (2) the multiple image is a function of visible persistence but the final percept is also mediated by other processes; (3) Di Lollo (1984) was in fact correct in his refutation of Type II persistence functions for low luminance stimuli; thus the techniques discussed so far in this section could all be evidence of an identical form of visual persistence. This last approach, however, apparently denies Long and McCarthy (1982).

Moving Slit Technique.

This method was used as early as the mid-nineteenth century by Helmholtz (1866). A stationary pattern is obscured by an opaque mask which has a narrow vertical slit in it, such that only a very small portion of the pattern is visible at any one time. However, if the slit is moved fast enough transversely across it, then the whole pattern becomes visible. This phenomenon might reasonably be explained by visual persistence (see Anstis and Atkinson, 1967). If the persistence generated by the primary exposure is still available by the time the slit exposes the

last portion of the pattern, then an image of the complete pattern is seen. A value for the duration of persistence may be calculated by finding the slowest speed at which the slit can move and still generate a percept of the complete pattern.

Haber and Standing (1969) found persistence, with this method, to be somewhere in the order of 300 ms. They also found evidence that persistence was reduced at high luminance.

Comment (Moving slit)

The stroboscopic and the moving slit techniques seem to be similar in principle. The comments that were presented earlier (relating to the former technique) would therefore also apply here.

Phenomenal Continuity.

The application of this technique is a variation on the cff method which has been discussed in a previous section (see page 16). A visual pattern stimulus is projected repeatedly but discontinuously in time. The maximum gap between successive projections that allows an observer to perceive the stimulus as being continuously present is taken as a measure of visual persistence.

This technique was first utilized by Haber and Standing (1969) where the stimulus was a black circle alternating with a blank field. They found persistence times of more than 250 ms and that its duration decreased with increases in stimulus luminance. Work in this field was extended by Meyer and his colleagues into the effect

of varying spatial frequency and grating orientation on visual persistence (Meyer, 1977; Meyer *et al*, 1975; Meyer and Maguire, 1977, 1981). The findings have generally been repeatable. Meyer and Maguire (1981), for instance, used vertical sine wave gratings of 0.4, 1.6 and 6.4 cycles/deg, projected at a space averaged luminance of 17.13 candela[1]/m^2. Persistence was found to decline as target duration increased from 50 to 500 ms, within each level of spatial frequency. Furthermore, there was a clearly positive relationship between persistence duration and spatial frequency. For example, with a 50 ms target duration, mean persistence duration was found to be just under 500 ms for the high frequency grating and just below 300 and 250 ms for the medium and low spatial frequency gratings, respectively.

Meyer and Maguire (1977) originally interpreted findings such as these in terms of "difficulty of processing". If a visual stimulus is rendered less discernable by reducing contrast or stimulus duration or by increasing spatial frequency (thereby introducing finer lines), then it may be profitable for an observer to extend the duration of persistence in order to maximise his information input. An alternative, and potentially more fruitful explanation is discussed in the following paragraphs.

Later work (e.g. Meyer and Maguire, 1981) has paid more attention to the separate sustained and transient neural networks that have been shown to mediate visual

[1]Unit of luminance usually abbreviated to cd/m^2:
1 cd/m^2 = 0.2919 fL

perception (see page 40).

The relationship between visual persistence and spatial frequency might be a function of the sustained neurone network. Since this network is more responsive to high spatial frequencies, then the higher the frequency, the greater would be the sustained response (Coltheart, 1980; Meyer and Maguire, 1981) . In addition to the findings cited above, Long and Gildea (1981) have obtained increased persistence at higher spatial frequencies with the RT technique. The inverse relationship between persistence and target energy parameters is a problem, for it would be expected that greater sustained network stimulation would give rise to stronger responses. It has, however, been proposed that activity in the transient network can inhibit activity in neighbouring sustained channels (Breitmeyer and Ganz, 1977; Breitmeyer, 1984). If this were so then this might serve as a mechanism for inverse effects. As Coltheart (1980) has speculated:

> "If the strength of this inhibitory effect were proportional to stimulus intensity, then the inhibition would be faster or stronger for intense stimuli than for weak stimuli. If so, visible persistence would be more effectively curtailed when the stimulus was intense than when it was weak".

It is interesting to note that Meyer and Maguire (1981) have endorsed this viewpoint. There do, however, appear to be two objections to this explanation. Firstly, Coltheart (1980) argued that persistence changes in response to luminance variations seem to him to be rather too large to be accounted for in this way. For instance, Allport (1970) found that persistence was reduced by about 50 ms when stimulus luminance was increased by 1.74 log units.

Secondly, Long and McCarthy (1982) found that full persistence duration could be induced to increase with luminance increases. In the latter example, as has been noted elsewhere, the target luminances used were too low to have produced even weak afterimages.

Comment (*Phenomenal continuity*)

The method of phenomenal continuity might be said to stand somewhere between direct measures of persistence duration (i.e. judgements of synchrony and RT methods) which clearly distil out the *visible* aspect in persistence and those measures that incorporate an extra component, by the integration of successive images (e.g. stroboscopic and moving slit techniques). The observer in the present (i.e. phenomenal continuity) setting is required to integrate across every other frame in order to maintain a perception of the continuity of a pattern, but unlike with the stroboscopic and moving slit techniques, this pattern is presented whole and invariant from the first exposure. It could therefore be argued that visual persistence measured by phenomenal continuity is explicitly visible all the time. Here again, however, Type I persistence functions are found with a task that ought to be measuring Type II persistence functions. The question of whether the nature of the persistence measured by phenomenal continuity is equivalent to that found by some more obviously direct methods remains open.

As discussed previously, particular interest has been focused on the problem of the locus of visual per-

sistence phenomena (i.e. whether persistence is centrally or peripherally generated). Clearly, if central processes are implicated then the importance of photoreceptor persistence may be diminished. However, even then the question of whether the different techniques measure similar persistence processes would not necessarily be resolved. In one experiment Haber and Standing (1969) report that there was no difference in persistence duration (measured by the phenomenal continuity method) when a circle stimulus was presented either monoptically or alternately to both eyes. They suggested that this must be evidence of a central locus of persistence. Their argument was that if persistence were a peripheral phenomenon then when the stimulus was presented to the alternative eye at the moment that the persistence generated via the other eye had ended, the stimulus should have been seen to be discontinuous. Coltheart (1980a) countered this argument by pointing out that if monocular channels fed into a central binocular channel that was "...indifferent to, or ignorant of, which eye is presenting input to it..." then phenomenal continuity would continue as long as either monocular channel remained active.

Temporal Integration of Form Parts.

At short SOA's a brief pattern stimulus (e.g. a letter) may be backwardly masked by subsequently projecting a visual noise (or a bright uniform field) stimulus, to a similar spatial location (see Breitmeyer and Ganz, 1976). One hypothesis that could account for this phenomenon is that the neural information generated by the fol-

lowing stimulus can integrate with the persistence trace generated by the first stimulus. This might result in a summated percept from which the contours of the first stimulus cannot be disentangled, thus resulting in a backward masking effect (see Navon and Purcell, 1981, for a more detailed discussion of this hypothesis).

Eriksen and Collins (1967) reversed this design, so that successful task performance depended on the ability to perceptually integrate two separate stimulus fields. They presented apparently random dot patterns in two stimulus fields such that when they were correctly aligned and superimposed a CVC (consonant-vowel-consonant) nonsense trigram could be clearly distinguished. They found that trigrams could be identified even when the stimulus fields were presented successively without any temporal overlap and that performance was a negatively accelerated function of inter-stimulus-interval[1] (ISI; performance declined as this variable was increased to 300 ms).

It is easy to see how the temporal integration of form parts (as this experimental paradigm is called) could be conceptually linked to backward and forward masking. In the former design temporally separate and spatially nonoverlapping visual elements perceptually combine to create the illusion of whole form. On the other hand, with masking, visual elements in successive fields may be spatially overlapping so that perceptual integration would result in reduced contrast (and/or

[1]The time period between 1st stimulus offset and 2nd stimulus onset.

increased visual noise), thus leading to impaired stimulus perception. It would, however, be misleading to state that the findings from these two empirical designs are caused by similar processes. The spatially overlapping masking paradigm could well be the result of erasure, rather than integration processes (see Navon and Purcell for a discussion of integration and erasure hypotheses of backward and forward masking, also Turvey, 1973; Coltheart and Arthur, 1972; Eriksen, 1980)).

Eriksen and Collins (1967) also investigated the effects of both stimulus field durations and found that performance was inversely related to each of these parameters (they used 4 stimulus duration levels ranging from 25 to 150 ms; stimulus luminance was 5 mL). They also noted that the impairment effect of the following stimulus duration was greater than that of the leading one. There were, however, two problems with their design that limited the power of their interpretations. Firstly, they used dark on light stimuli which meant that there were overlapping visual features between stimulus fields. It is therefore possible that masking effects mediated in the integration processes; the light areas of one field would spatially overlap with the light and dark areas of the other field. This may have meant that the dual field interaction was accompanied by other processes besides integration. Secondly, they used constant intensity stimuli so that apparent brightness and duration were confounded due to the operation of Bloch's Law. Since

they could not distinguish between stimulus energy and stimulus duration effects, they favoured the more intuitively satisfying hypothesis that stimulus duration effects were caused by apparent variations in stimulus field contrast.

When Eriksen and Collins (1968) used light on dark stimulus fields and manipulated stimulus intensity instead of duration, they found that contrast differences between fields *did* impair performance. They apparently took this as a vindication of their hypothesis and for a number of years afterwards the duration parameter was forgotten. At this point in time therefore, visual persistence measured by both partial report and temporal integration methods could be considered to be synonymous. They could both be explained in terms of a decaying visual persistence trace that was generated at stimulus offset. This conforms to the concept of Type II persistence (of course at this date the concept of Type I persistence had yet to be proposed).

Nevertheless, they pointed out that there were anomalies that could not be accounted for by a simple decaying trace theory. When both fields were of equal luminance, performance deteriorated only marginally as stimulus energy decreased. They mention that performance declined from 88% to 80% as luminance was reduced from 2 mL to 1 mL, with simultaneously presented and equal intensity fields. According to the decaying trace hypothesis, the 5-2 mL (these figures represent the respective luminances of the leading and following fields) and 5-1 mL conditions should, at some ISI, have equalled

performance in two low luminance, simultaneously presented, fields (where luminance was 1-1 and 2-2 mL). This did not happen; performance in the unequal luminance conditions was always below 80%. Eriksen and Collins therefore concluded that whilst some of the data could be explained via a decaying trace hypothesis, another factor influencing visual (i.e. temporal) integration was involved. They speculated that this factor might be discontinuity detection. In other words, integration may have become disrupted by the temporal discontinuity between stimulus fields. It might be speculated that this could have been detected via the offset of the leading stimulus field or the onset of the following field or even by some property of the blank ISI period.

Cohene (1975) used the successive field integration technique with bright dots on a dark background. Field durations were investigated where the fields were of equal length. Performance deteriorated as stimulus duration increased from 25 to 75 ms, at all ISI values which ranged from 0 to 40 ms. The stimulus energy was not equated across duration conditions, so these results could be interpreted to mean that integration performance declined as stimulus energy increased. Pollack (1973) also found an inverse relationship between stimulus duration and integration performance and speculated that brightness was the "relevant variable". Seemingly, improving the perceptual quality of the individual successively presented fields was a negative guarantee for temporal integration.

Both Cohene and Pollack speculated as to the in-

volvement of discontinuity detection. Presumably any change in a brighter or longer duration stimulus would have a greater probability of being detected, and thus initiate perception of discontinuity, than in the case of a less energetic stimulus (see also Hellige *et al*, 1977, 1979).

The idea that discontinuity detection functions to limit integration is questionable, however. Kinnucan and Friden (1981), using a pattern-only temporal integration task (missing dot task - See below), confirmed that bright followed by dim fields gave better integration performance than the reverse presentation order. In a second experiment, observers were required to rate similar stimuli for the completeness of apparent integration. It was found that apparent integration could be rated poorly even when performance in the first experiment had been relatively good. They concluded that even where discontinuity was detectable, this did not limit a subject's ability to visually integrate the successively presented stimuli.

Hogben and Di Lollo (1974) developed an elegant variation on the successive field presentation paradigm. 24 dots were plotted in fast temporal succession. Each dot appeared on the screen for only 50 μs with negligible rise and fall times (approximately 5 μs, either way). The spatial arrangement of the dots was in the form of a 5 x 5 square dot matrix with one dot missing. The subject's task was to identify the missing dot location. It seems quite reasonable to suppose that above chance performance in the task would have been virtually impossible without

some degree of temporal integration of the successively presented dot elements. The results showed, as might be expected from the above mentioned research, that errors increased monotonically as the inter-dot plotting interval increased from 40 to 280 ms. In another experiment the 24 dots were plotted in 2 bursts of 6 followed by 18 dots, separated by a variable blank inter-burst-interval. Again, as expected, performance declined as this factor increased. Data from the serial plotting and burst plotting experiments were compared on the basis of equal total plot durations. This revealed that the increased gap interval in the burst condition had a greater inverse effect on performance than could be explained in terms of a decaying trace hypothesis. For example, in one pair of experiments, in a condition where the total plot duration for both burst and serial plot conditions was 120 ms, the gap intervals were 90 and approximately 5 ms respectively. Now according to a simple decaying trace theory, performance in the serial plot condition should either have been equal to or worse than the burst condition. This is because in the serial plot condition more dots would have suffered persistence decay by the time the last dot was plotted. However, a comparison of results indicated otherwise. Mean errors in the serial condition were less than 20%, whilst in the burst condition mean errors rose to over 50%. This discrepancy was, in fact, found at all plot durations ranging from 40 to 200 ms.

On the basis of these and other similar experiments Hogben and Di Lollo concluded that there was another process, as well as decaying dot persistence, that inhib-

ited perceptual integration. Metacontrast masking was considered because errors tended to be made to locations which had been occupied by dots presented earliest in a presentation sequence. However they pointed out that this type of masking should give rise to an inverted *U* function with its peak at around 50-100 ms and their results showed "...no trend in that direction". They therefore considered that a more likely consequence of the gap was to increase the probability of discontinuity detection and that this, in turn, might have reduced the probability of perceptual integration. However, if Kinnucan and Friden (1981) were correct in their evaluation of discontinuity detection then some other explanation is warranted. It may be that these effects reflect some property generated by an ISI period itself rather than the holistic impression of discontinuity.

Di Lollo (1977, 1980) used a similar missing dot technique to provide evidence to show that the duration of visible persistence might be more properly measured from stimulus onset, rather than offset. Twenty-four dots were presented in two temporally successive groups of twelve dots each, separated by a constant 10 ms ISI. The first group of dots (S1) was projected effectively simultaneously for variable durations, ranging from 10 to 200 ms. The second group (S2) was always presented for a constant period of 10 ms. Furthermore the luminance of S1 dots was adjusted so that apparent brightness remained constant at all durations. Performance was virtually error free at the 10 ms S1 duration but increased up to between 60% and 80% for the 200 ms duration. Di Lollo

suggested that this result could be accounted for if "...sensory persistence of the contents of the leading display diminished sharply after exposure durations greater than about 100 msec".

In a further experiment, the 24 dots were projected serially over a period of 230 ms. All but one of the dots were presented for 1.5 μs at an inter-dot-interval of 10 ms. The twelfth dot to offset in the series had its onset from the time of plotting the 2nd dot, thus giving it a total duration of 100 ms. Di Lollo reasoned that if SOA was the key measurement for visible persistence, then the probability of making an error in the twelfth dot location would be equal to errors in the second dot location. Alternatively, an hypothesis based on persistence decaying from stimulus offset would predict that the 12th dot error probability would be somewhere between that of the 11th and 13th dots. In the event, the probability of error was shown to be approximately equal to that of the 5th dot. While noting the discrepancy between prediction and results, he concluded that persistence duration had been reduced for the twelfth dot and that, even though he expected it to be reduced even further, the discrepency was minor enough to uphold the SOA hypothesis.

The failure of this experiment to provide unqualified support for the SOA hypothesis should not have been a total surprise. Hogben and Di Lollo (1974) also found that variations in 1st field duration and ISI were not equivalent. The latter parameter had a greater effect on integration performance than the former. Hogben and Di Lollo interpreted their findings in terms of an enhanced

probability of discontinuity detection. In the present experiment, no such clear explanation is warranted. Since the elements in the display, in this case, were presented serially there would most likely have been a continuous perception of discontinuity over different parts of the display. It seems unlikely, therefore, that the discontinuity of the 12th dot would have been more or less salient than the rest. The empirical evidence from these two experiments points to an inverse relationship of performance with both 1st field duration and ISI but not to a straightforward SOA relationship.

In two follow up experiments Di Lollo (1980) presented a target and a pattern mask so that their offsets coincided. The duration of the target was always 10 ms but the target was presented at varying SOA's from 0 to 640 ms. He found that whilst masking was effective at 0 ms (between 70% and 80% error rate), this declined rapidly in a monotonic fashion as SOA increased. When SOA was 160 ms, errors averaged less than 20% and began to asymptote. Di Lollo's explanation was that when the mask was long only the persistence from the target survived stimulus offset, thus allowing it to be identified. These experiments therefore provided convincing support for the notion that persistence processes are generated at stimulus onset and endure for between 100 and 200 ms.

An alternative explanation for the above mentioned findings in terms of any form of the psychological moment theory would appear to be unlikely. Di Lollo and Wilson (1978) did, however, test the moment theory but found no support for it (see also Breitmeyer, 1984, for a

discussion of this topic).

The results discussed in this present subsection lead to inevitable comparisons with measures of visual persistence obtained via other techniques. Recent findings have implicated sustained and transient cells (particularly the former) as possible mediation mechanisms for visible persistence (see page 40). Di Lollo and Woods (1981) used the missing dot technique to investigate the effects of varying spatial frequency on integration performance. In this case, each element was a square sub-matrix consisting of 3 rows, each containing 3 dots. Spatial frequency was manipulated across 4 levels by inserting any of four defocusing lenses in front of observers' eyes. They calculated that the highest spatial frequencies which were resolvable through them were 60, 3.49, 1.71 and 1.41 cycles per degree. Using both the twin burst method, with a variable ISI (ranging from 15 to 155 ms; each burst lasted 2.5 ms) and the serial presentation method (plot durations ranged from 20 to 160 ms), they showed that performance decreased with decreasing spatial frequency at all but the most extreme durations. The extreme durations seemed to coincide with floor and ceiling levels of performance.

During the course of this research they also ran similar experiments to test the effects of luminance and visual angle. Luminance was tested with the burst method, for the fully focused display at three levels of brightness, ranging from 3.4 to 1.4 log units above threshold. Performance increased with dot luminance. However this effect was only found at the shorter S1 durations (less

than 100 ms), when integration should have been best. Di Lollo and Woods argued that these findings were commensurate with changes in the clarity of the overall display, rather than in visible persistence *per se*. Visual angle was varied in two ways: (1) By increasing the spatial separation of elements of a display by changing the screen plot locations (the overall size of the display was not affected); and (2) by increasing the subject viewing distance (overall matrix visual angle varied from 6.64° to 3.0°). Method (1) showed little effect of increasing inter-element separation from 0.5° to 1.0°. Method (2) showed a very slight but consistent advantage to the smallest visual angle.

Di Lollo and Woods favoured an explanation of the above results in terms of changing persistence durations as a function of the degree of high spatial frequencies present in a display. As high spatial frequencies were progressively eradicated so sustained channel activity was reduced. This would lead to less persistence at the longer SOA's which, in turn, would reduce the probability of temporal integration.

Transient activity works in the opposite way, in that its latency is reduced and its response strength is increased with decreasing spatial frequency. Visual integration phenomena might not simply be a function of the degree of persistence overlap but also might in some way be inhibited by transient responses. The results discussed above could then be reflecting a transient rather than sustained factor.

Two further experiments seem to imply that a sudden

change of the visual aspect of the leading stimulus can enhance integration and therefore seem to implicate transient neural activity. The first (Di Lollo, 1980) was another missing dot experiment where each element in the matrix was made up of 3 dots formed into the shape of an upward pointing equilateral triangle. The 12 dots in each of the leading and final fields were presented as two discrete stimuli and ISI and the following field duration were kept constant at 20 and 10 ms respectively. The duration of the 1st field was varied across 6 levels, between 10 and 200 ms. In another set of conditions, consisting of similar durations, the triangular elements of the first field were rotated by 180° for the last 10 ms of its presentation. The unrotated condition gave rise to the familiar inverse performance-duration effect. However, the rotated condition showed near perfect performance (less than 20% error). He argued that these results indicated that persistence duration was a function of "...the duration of local detail" rather than of "...exposure duration of overall configuration". The latter quotation refers to the alternative but discredited hypothesis that once the perception of the unitary form of the first field had been achieved (in that event local detail would be largely irrelevant), then integration of an aftercoming stimulus would be inhibited. His final conclusion was as follows:

> "A change in local detail (rotated condition) generated a new lease of persistence, which enabled perceptual bridging of the temporal gap despite the unchanging overall configuration of the leading display".

In the second experiment mentioned above, Di Lollo

and Bourassa (1983) showed that a similar *regeneration* effect could be obtained by merely brightening the elements (from approximately 0.8 to 2.06 log units above threshold) for the last few milliseconds of the leading display. Moreover, they showed that performance was inversely related to the brightened flash duration, regardless of the duration of the leading portion of the 1st field (i.e. the dimmer dots). No effect on performance was found by varying the luminance of a 20 ms duration 1st field from between 0.8 and 2.0 log units above threshold. Obviously therefore, these results could not be explained by simple differences in overall brightness conditions in the leading stimulus field. More likely, the regeneration process noted by Di Lollo (1980), and caused by the change of local detail, could also be induced by a sudden brightening of stimuli to the same retinal location.

Sakitt and Long, in pursuit of their photoreceptor hypothesis of visual persistence (their point of view has been discussed in a previous subsection), have also undertaken successive field experiments using various types of stimuli (Long and Sakitt, 1980a, b; Sakitt and Long 1978, 1979). Their findings have confirmed that integration performance is inversely related to ISI. They claim, however, positive stimulus intensity and duration effects are more frequently obtained.

Long and Sakitt (1980a) presented two rectangular outlines, which were temporally successive but spatially adjacent (side by side). In 50% of trials the adjacent sides successively occupied the same spatial location, on

the rest they were separated by a narrow gap (6.9′ for an inexperienced observer and 4.1′ for an experienced one). The observer's task was to determine, in a forced choice situation, whether or not there was a spatial gap between the two sides. It was found that where ISI was 100 ms or greater, then performance was positively related to stimulus luminance (this included a range of relatively dim stimuli) and also positively related to 1st field duration (ranging from 15 to 500 ms). However, for the 20 ms ISI condition stimulus duration gave rise to an inverse relationship with performance.

The latter findings (about inverse duration effects) were contrary to the investigators' expectations and they attempted to reverse them, with limited success. The experienced observer did manage, with extended practice, to turn the inverse relationship into a positive one. Extended practice for the inexperienced observer, on the other hand, merely (and only partially) flattened the negative slope, although the inverse relationship was never totally lost. As with similar studies discussed earlier, the rationale behind this experiment was that performance would be facilitated when 1st field persistence overlapped with the 2nd field. However, these researchers, unlike the majority of investigators, expected to show that persistence duration was positively related to stimulus intensity.

This experiment is not entirely convincing. With such a simple discrimination task it could be that observers would be able to use other strategies (besides integration) in order to successfully complete the task.

The merest scratch or speck of dust on the projection surface might have acted as a spatial cue and thus might have served to fix the position of stimuli. Alternatively, in Long and Sakitt's experimental setup the small continuously illuminated central fixation light, that was positioned at a location where the gap could appear, might well have been sufficient for this purpose. Any increase in stimulus luminance or duration might then serve to enhance the value of extraneous clues. Similarly, with extended practice, familiarity with the display apparatus might have improved the subject's ability to take advantage of incidental spatial cues.

In contrast, an observer in Di Lollo's experiments would have been unlikely to benefit from similar extraneous clues, due to the complex pattern in each stimulus field. Furthermore, most of his subjects were highly practised and there were no signs that the inverse duration effects were lessened by this fact.

Comment (*Form part integration*)

The Eriksen and Collins paradigm, as this technique is sometimes called, is of particular relevance to the subject matter of this thesis, since most of the empirical work reported in Chapters 2 and 3 has made use of it. The fact that Di Lollo and his colleagues used energy equated stimuli and still found clear inverse duration effects (for the leading stimulus field) underlines the importance of this stimulus parameter. Indeed, the similarity between these results and those generated by other so called direct methods is tantalizing. Yet

again, a Type II task has been found that shows evidence of Type I persistence response functions.

In another way, though, the concordance between the different techniques is not so clear cut. As discussed above, Di Lollo and Woods (1981) obtained little effect of stimulus brightness. Eriksen and Collins (1967, 1968) and Long and Sakitt (1980a, b) did provide some evidence for positive stimulus energy effects. Bowen *et al* (1974), using the judgement of synchrony method, showed that visible persistence was constant for flash durations below about 100 ms, when stimulus energy was equalised. This seems to reinforce the suggestion made above (see comment on stroboscopic technique), that visible persistence as measured by judgements of synchrony and RT to flash onset and offset are not comparable with successive field methods. Furthermore, an energy independent but spatial frequency dependent form of visual persistence would seem to place its locus well beyond the photoreceptor level.

Di Lollo's partial failure to show that visual persistence should be measured from stimulus onset has highlighted the possibly independent roles of both the leading stimulus field duration and ISI, in the temporal integration process. This exacerbates an already complex problem since it is difficult for a simple hypothesis of integration to explain why the negative functions of both parameters are probably different. With a passive integration model, where a fading persistence trace (generated at stimulus onset) perceptually combines with a following stimulus, the only temporal parameter of conse-

quence (assuming equal energy stimuli) would be SOA.

Coltheart (1980a) made two pertinent suggestions regarding this finding: (1) that persistence should actually be measured from offset and "...that there is a decreasing negatively accelerated function relating stimulus duration to persistence duration."; or (2) "...there are actually two persistences, one generated by stimulus onset and the other generated by stimulus offset; their durations are both independent of the stimulus duration, but the onset persistence is, on average, longer lasting than the offset persistence".

One stimulus parameter that has been largely overlooked in temporal integration studies is that of the following stimulus duration. As mentioned above there is some limited evidence that this factor may also be important to integration performance. If visual integration were dependent on the absolute rather than relative durations of two successively projected fields, then the results of both Eriksen and Collins (1967) and Cohene (1975) would suggest an inverse relationship between both the leading *and* following stimulus field durations and integration performance; caution needs to be applied here, since both these studies used black on white stimuli so that possible masking effects may have influenced results. In fact, it is not surprising that this duration parameter has been generally ignored by researchers. The main theories about integration would predict, at best, only a minor role for following field duration. Nevertheless, it will be argued in later chapters that effects caused by varying following stimulus

duration should stimulate a fairly drastic reinterpretation of the integration process itself.

The techniques discussed above have been relegated to the category of direct methods by Coltheart (1980a, b). As such, they are held to reflect the operation of *visible* persistence (there is little general disagreement on this point). This may be a dangerous assumption to make since there is no solid evidence for it. As will be discussed later in this chapter, Di Lollo (1980) argues that visible persistence reflects the feature analysis stage of visual processing. Now, if by *visible* he meant *perceived* (i.e. where all the feature elements of the stimulus are seen correctly in their correct spatial relationships) then this could not occur until feature analysis has been completed. In fact, Di Lollo (1984) made it quite clear that he means a *sensation* that is devoid of explicit form information. However, subjects do not report the existence of a formless visual sensation after dim but suprathreshold successive display presentations. The proposal that visible sensation persists at the brief intervals that Di Lollo employed can be little more than conjecture. Moreover, some of the work that is reported in later chapters of this thesis may well preclude this idea as a useful concept for understanding temporal integration.

Stereoscopic Persistence.

Engel (1970) used dichoptic presentations of two slightly different random dot matrices. Each matrix contained about 10,000 light elements where the brightness

distribution between them was similar. The matrices were designed so that when they were viewed in synchrony they fused to give the impression of a stereoscopic image, in the form of a central sub-matrix which was seen at a different depth from its surround. No clue, regarding the existence of the three dimensional sub-matrix, could be obtained by viewing either dot matrix singly. Using the phenomenal continuity technique, he was able to measure the duration of monocular persistence by determining the maximum SOA for presentations between eyes that still preserved the stereoscopic sensation. Similarly, by extending the ISI between the offset of the second stimulus of the pair of dichoptically presented matrices and the onset of the next successive paired presentation, a measure of the duration of stereoscopic persistence could be obtained. He found that monoptic persistence increased as a function of increasing stimulus energy, up to a maximum of approximately 80 ms. Stereoscopic persistence could extend as long as 300 ms. The stereoscopic persistence increased as the degree of monocular response overlap increased. The minimum overlap required for stereoscopic perception was about 4 ms. Engel concluded that his results indicated the existence of two persistence stages as evidenced by the differential durations between monocular and stereoscopic responses. He speculated:

> "Presumably the first stage is at the retina and the second stage is at the point in the nervous system where the monocular channels interact. It appears that the second stage functions not only to fuse the monocular inputs but also to regenerate the combined monocular signals in that it was found that the duration of the stereoscopic

> response was always longer than the duration of monocular overlap and was, for the most part, longer than either monocular response. It would appear that this second stage is peculiar to the process of fusion".

It is interesting to note that Ross and Hogben (1974) attempted a similar study using dot matrices in order to induce stereoscopic sensation. Their results closely paralleled Engel's. They found that stereopsis failed when the SOA between stimulus pairs exceeded 70 ms.

Comment (Stereoscopic)

The above mentioned findings are important in that they clearly identify a more centrally generated locus for at least one form of persistence. The indication that information from monocular channels was fused and re-generated at a post-retinal site suggests intriguing possibilities for other phenomena mentioned above. It may be, for instance, that this more central form of persistence has implications for form part integration tasks (these might also conceptually include the stroboscopic and moving slit methods).

Engel's finding that monocular persistence duration was positively related to stimulus energy would seem to be at odds with those studies that imply an inverse energy-duration relationship (see above).

General Conclusions

The general consensus regarding direct investigations is that persistence duration is inversely related to stimulus durations (below some critical value of be-

tween 100 and 200 ms). This is a compelling argument for the idea that perception has a minimum duration (Efron, 1970a) and for the not so very different proposal that visible persistence is of constant duration and is generated at stimulus onset (Di Lollo, 1977, 1980).

Nevertheless, there are some results that appear to challenge this reasonable (although perhaps counter intuitive) hypothesis. Firstly, the stimulus intensity parameter does not function similarly across all the direct techniques. With judgements of synchrony, when intensity is adjusted to maintain energy equivalence between different duration stimuli, then persistence does not vary with absolute stimulus duration (for stimuli below the critical duration). In contrast to this, inverse stimulus-persistence duration effects have been consistently obtained in the temporal integration paradigm, even when intensity was adjusted to maintain brightness equivalence. This seems to raise doubts about whether the two techniques are measuring similar processes. Secondly, Long and McCarthy's (1982) findings that Type 1 and II persistence functions can be obtained with the judgement of synchrony and RT techniques (depending on the instructions given to S's), raises the question of whether these techniques actually *do* measure visible persistence phenomena. Thirdly, the failure by Di Lollo (1980) to obtain exact reciprocity between the stimulus element duration and ISI in temporal integration investigations (see above) does not entirely favour the view that persistence is generated at stimulus onset. Coltheart (1980a) has suggested that there may be two persistences, one gener-

ated at onset and one at offset. But another explanation that might also fit these results is that there may be two different processes operating during integration tasks. Only one of these would be decaying persistence, the other process might operate in a different way to inhibit integration. The alternative may be that Di Lollo was correct and that the small discrepancy from total reciprocity was due to an anomalous experimental artefact.

One tentative observation in this subsection was that the 2nd field duration may play some role in the temporal integration process. It was pointed out that the experiments in which this effect was noted did not equate successive field energies, and it may be that it would disappear if this were done. Even if the effect was robust, it would be difficult to explain it in terms of conventional models and it may only play a secondary role in the integration process. Nevertheless, it is worth mentioning this factor here, since considerable interest is directed towards it in later empirical chapters.

It is difficult to reach any final conclusion about visual persistence as measured by direct methods. Leaving aside the controversy about why some researchers obtain positive duration effects whilst others obtain negative ones, there are enough anomalies between apparently concordant findings to raise the suspicion that at least some of the direct techniques do not give rise to pure persistence measurements. The alternative to this is that there are more different forms of persistence than have been identified so far. It may be that some of them

relate to peripheral processes whilst others are generated by more central mechanisms.

1.7 Information Processing Theories of Visual Persistence

Theories of visual persistence fall into two main groupings: (1) That most (or perhaps all) persistence manifestations are generated by peripheral mechanisms and relatively slow fading neural traces; or (2) that some persistence is generated in central processing areas at the cortex and reflects underlying cognitive mechanisms needed to recode the original visual input into meaningful perceptions.

This section is concerned with the latter approach; three main hypotheses are discussed. The influence of Coltheart (1980a, b) will become apparent as two out of the three hypotheses to be discussed could not be serious contenders without an acceptance of the dichotomy between direct and indirect methods. Not surprisingly, investigators, who are interested in this approach, obtain much of their data from variations of the partial report technique.

Two of these models were mainly developed through empirical PR work and therefore have little to say about the divergent results obtained by direct studies. The third hypothesis was developed mainly (but not entirely) through temporal integration techniques and, whilst its predictions for PR are compelling, they are not well supported by the greater body of (PR) research.

Dual Buffer Model

This model was proposed by Campbell and Mewhort (1980) (see also Mewhort *et al*, 1981, 1984) on the strength of empirical data from partial report. It consists of four processing stages operating within a feature buffer and a character buffer. This model was developed using PR techniques and, as mentioned earlier (page 35), the idea that spatial and identity information is coded separately was introduced in order to account for the differential production of mislocation and intrusion errors:

Stage 1: "Features extracted from the stimulus array are stored in the feature buffer". They proposed that this feature buffer has unlimited capacity and "...preserves spatial and other physical attributes of the display". The data held at this stage are still of a precategorical nature.

Stage 2: A *character identification mechanism* uses information about a letter's shape and frequency as a means of identifying the letters in the display. This mechanism "...produces an abstract representation of each character, a process that involves data reduction". Some, but not all, of the physical attributes of the display are coded with identity codes. Hence they describe the actions at this stage as a *selective process*. Intrusion errors result from imperfect operation of the character identification mechanism.

Stage 3: The output from Stage 2 is stored in a character buffer, "...it is postcategorical, but it preserves the relative spatial position of the letters".

Spatial information here is subject to decay and can be masked.

Stage 4: At this point an *attentional mechanism* searches for an item in the character buffer, and is directed by the spatial instructions from the probe. The item is then transferred to be stored in short-term memory, where it awaits report.

According to this model most errors are those of mislocation and are produced at the character buffer level. They postulate that in partial report trials where no mask is used, then identification should be excellent but mislocation errors will predominate. Thus they state that "...when accuracy of report declines as the probe is delayed, the loss should reflect increasing spatial uncertainty at the character buffer, not a loss of letters or of preletter feature information". Items may be masked differentially at the feature buffer and character buffer stages. At the former stage, feature information is disturbed, resulting in a loss of efficiency in the character identification mechanism. Thus, it is due to processing faults at this early analysis stage that misidentifications (and hence intrusion errors) occur. Therefore the early presentation of a mask should cause an increase in item errors. Later masking at the character buffer level "...is thought to increase spatial uncertainty. If subjects lose spatial information, location errors should increase".

Comment

One important feature of this hypothesis is that

partial report performance depends on item selection at a postcategorical processing stage. In the first decade of iconic memory investigation, this idea would have been untenable because no partial report superiority could be achieved with postcategorical cues (see page 30). However, evidence that there can be small partial report advantages with postcategorical cues has recently come to light (Merikle, 1980; Duncan, 1982).

This model appears to be attempting to meld ideas of visible and information persistence. Presumably, visual data at the feature buffer stage is the source of visible persistence whereas data in the feature buffer generates information persistence. If, as evidence from direct studies suggests, the duration of visible persistence is constant from the moment of stimulus onset and if, furthermore, the character identification mechanism can complete its work prior to the end of visible persistence then the physical duration of the stimulus array would make little difference to partial report performance. Thus, on initial consideration, there is no conflict between the dual buffer model and results from direct techniques from which inverse effects of stimulus duration on persistence duration are implied.

The problem is that if postcategorical buffers can maintain spatial information for a time then why is it that tasks, generated by other experimental techniques such as the Eriksen and Collins paradigm cannot take advantage of this mechanism? If they could then the inverse duration effect demonstrated by Di Lollo (1977, 1980) should not have occurred.

Two Stage Model

The main features of this model were proposed by Yeomans and Irwin (1985) and extended by Irwin and Yeomans (1986). This is a more serious attempt at encompassing evidence from direct and indirect investigation techniques but, here again, the empirical basis for the development of this model relied entirely on partial report techniques.

As the name of the model implies, there are two stages, the first of which is visible persistence, produced as a by-product of neural persistence. They called this the *sensory representation*. At the same time as this a precategorical *visual analogue* is also constructed and endures for 150 to 300 ms, regardless of stimulus duration. The information contained in the visual analogue is sensitive to the physical characteristics of the inducing stimulus and is susceptible to masking.

In the second stage, precategorical information from the sensory representation and visual analogue is converted, via a *translation* process, into *nonvisual identity codes* containing "...some relatively poor coding of spatial layout". This stage is held to be impervious to visual masking. Prior to probe onset the translation process is nonselective and items may therefore become recoded arbitrarily. However, after the probe is registered, then the translation process selects only cued items for recoding. Recoded items are transferred to *short-term memory* for later recall.

Comment

This model has many similarities to the previous one. It differs mainly in two ways: (1) Masking only operates at the precategorical stage here whereas, for Mewhort *et al*, it operates differentially at both pre- and postcategorical stages; and (2) item selection has its source at the precategorical stage but Mewhort *et al* state that the cue acts at a postcategorical stage.

Nevertheless, the criticism here is similar to the previous one. If the visual analogue contains full spatial information and this information is not lost until at least 150 ms after stimulus offset then it is difficult to see why temporal integration tasks should not be able to make use of it. Here again, if they could then there would be no inverse duration effect .

Two Phase Model

Di Lollo (1980; see also Di Lollo, 1978) proposed that a number of different processing operations were involved in the perception of form. Some of these operations would be processed in parallel, whilst others would proceed serially. Out of these diverse processes he concluded that two phases, which he called *recruiting* and *interpreting*, could be broadly categorized. Their attributes were hypothesized to be the following:

Phase 1 - Recruiting: This is the processing phase that is hypothetically associated with *visible* persistence. The stimulus undergoes a process of *feature encoding* "...in terms of as yet meaningless features such as dots,

bars, edges and discontinuities". The codes that emerge from this phase then become available for further processing in the next phase. In Di Lollo's words, characteristics of the recruiting phase are as follows: "...(a) faithful maintenance of stimulus geometry with initial retinal configuration; (b) virtually unlimited processing capability; (c) mainly parallel processing; (d) masking through integration of contours (as distinct from interruption of processing...); and (e) sensory persistence (namely the maintenance of physical, as distinct from informational, aspects of the display)".

Phase 2 - Interpreting: Identification and categorisation operations are performed in this phase. The eventual output contains ***meaning encoded*** items that become available for "...more complex processes of organization and for more permanent forms of memory". The characteristics of this phase are hypothesized as follows: "...(a) mainly serial processing; (b) little if any correspondence between stimulus geometry and initial retinal configuration; (c) masking by interruption of processing; and (d) maintenance of informational rather than physical aspects of the display (i.e., absence of visual persistence)". It is assumed here that by "visual persistence", Di Lollo means visible persistence. It is at this stage that spatial information is lost.

In order to account for the inverse duration effects obtained via direct techniques of investigation, Di Lollo proposed that the work of Phase 1 becomes completed in

100 to 200 ms.

The obvious loophole is that if information is constantly being transferred from the eye to the recruiting processors then there should be no loss of spatial information with increasing stimulus duration. This should only occur with increases in ISI. However, Di Lollo proposed that old contours are not normally reprocessed so that extending stimulus duration would not improve spatial perception.

In order for this idea to be viable, the feature processing system must have a way of distinguishing *new* contours from *old* contours. Evidence for this was provided by Di Lollo and Bourassa (1983: see page 70) when they demonstrated that the system might be fooled into re-analysing old contours by brightening display elements. It seemed to them that the transient neural network which is known to register 'on' responses might be a good candidate to operate this mechanism.

Comment

This model provides a reasonable explanation for many of the findings of so called direct methods. Although it is parsimonious by virtue of its attempt to propose a unified persistence theory, it still fails to explain the lack of stimulus duration effects in PR. According to this hypothesis, they *should* occur.

Conclusions

The common feature of all these models is that spatial information is held to be less robust than identity

information. This, in turn, conjures up the idea that items begin to perceptually "drift" from their respective locations after stimulus offset and that this is the main source of error in partial report tasks. Clearly, as perceptual drift becomes more pronounced the probability of correctly locating array items would decline. This would induce mislocation errors but, since identity codes are held to be relatively robust, intrusion errors would not necessarily increase. As discussed earlier, most PR errors are, indeed, transpositions (mislocation errors) and, hence, the notion of perceptual drift appears to fit the empirical facts.

These models are extremely limited in their capacities to deal with findings resulting from anything but the original research methods. Both the dual buffer model and the two stage models, which purport to explain partial report performance, also include a precategorical feature analysis stage. Presumably this stage would be indiscriminate in its operations, and would not differentiate between stimuli relating to lexical as opposed to pattern-only information. Thus, the question as to why stimulus duration has an inverse effect on temporal integration (where pattern-only and alphanumeric stimuli are used) in direct opposition to partial report findings (where alphanumeric array items are generally used) remains unanswered by these hypotheses. It may be that Coltheart's distinction of multiple types of persistence is correct but for this to be a useful explanation for the differences between PR and TI techniques, it is still necessary to explain why temporal integration performance

is unable to make use of information persistence.

Di Lollo's two phase model suffers from the opposite problem. He adequately explains the inverse stimulus duration-persistence duration relationship, but fails to account for its lack of manifestation in partial report experiments.

In conclusion, therefore, the empirical evidence presents powerful arguments for the idea of multiple forms of persistence. Nevertheless, it seems counter intuitive and perhaps premature to explain the differences between PR and temporal integration in terms of divergent processes. Both techniques usually require the presentation of two stimulus fields (except where an auditory cue is sometimes used in PR) and there is no obvious reason why the phenomenal experience of perceptual integration would not be useful in PR tasks. In Chapter 4 the functional similarities between direct and indirect tasks (as opposed to their differences) are examined in greater depth.

1.8 Summary

It was pointed out in the introduction that the phenomenon of temporal integration has become conceptually linked with visual persistence. Indeed temporal integration has often been regarded as a special case of persistence manifestation and, as such, has rarely been accorded much interest in its own right. This has led to integration techniques becoming used as tools for the study of persistence. For this reason much of the present chapter has been directed towards reviewing studies of

persistence regardless of whether temporal integration was directly involved in these.

The main psychological moment theories were discussed as an alternative approach to the investigation of visual persistence and related phenomena. The only version that was supported empirically was the *travelling moment hypothesis*. However, this hypothesis was held to provide little explanatory power and most investigators have concluded that the idea of persisting visual information is a more useful concept to work with.

The partial report superiority effect was discussed and it was shown how this technique could be used to measure visual persistence, or iconic memory, as it was later to be called. Early investigators concluded that iconic memory was a rapidly decaying precategorical visual memory store that was generated at stimulus offset. Most estimates of iconic memory duration were in the region of 500 ms (but some investigations have obtained values of up to 5 seconds).

It was pointed out that there is current controversy regarding the direction of stimulus duration and intensity effects on persistence duration. Many techniques indicated that persistence was inversely related to both stimulus parameters and this was contrary to the findings from partial report methods. An influential paper by Coltheart suggested that those techniques that gave rise to inverse relationships ("direct" methods) were, in fact, measuring *visible persistence*, whilst partial report (an "indirect" method) measured *information persistence*. Partial report findings were discussed further and

the idea that there may be differential rates of loss for spatial and identity information was introduced. This reinforced the idea that visible persistence is not implicated by this technique.

Types I and II persistence functions were discussed as an alternative explanation for the positive and inverse effects of stimulus duration. This was held to be a promising hypothesis but when the various direct methods were examined in more detail, it was found to be untenable.

The Eriksen and Collins paradigm was examined extensively and Di Lollo's hypothesis that visible persistence processes are generated at stimulus onset, and expire between 100 and 200 ms after this, was discussed. Although this appeared to explain many of the results from direct methods, it was pointed out that there were anomalies in his (Di Lollo's) data that rendered his conclusions questionable. There were also other findings (such as the possibility that integration might be influenced by the duration of a following field) which led to the speculation that temporal integration might depend partly on hitherto undiscovered processes.

The striking concordance between all the direct methods with regard to the effects of stimulus duration on persistence was noted. However, in contrast, it was also noted that intensity effects were more varied. It was pointed out, for example, that persistence duration was invariant (for stimuli below the critical duration) with the judgement of synchrony method, when stimulus energy was taken into account. This was not the case with

some temporal integration experiments. There, stimulus duration effects remained robust regardless of whether energy equivalence was maintained.

Finally, various current hypotheses were considered with particular emphasis directed towards information persistence. It was pointed out that these could not be acceptable universal theories (even though at least one of them purported to be so) because their predictions could not encompass findings from both direct and indirect research methods.

1.9 Preview of Remaining Chapters

The research in the first section of Chapter 2 is concerned with exploring duration effects in successive field presentations of stimuli containing letter parts. Both the temporal integration of form parts and backward masking paradigms are considered, with particular regard to a hitherto largely ignored temporal parameter.

The second section of Chapter 2 extends the temporal integration work, this time using pattern only stimuli. The experiments that are reported here manipulated the extra dimension of stimulus intensity in order to unconfound duration and brightness.

Hypotheses generated by the empirical work in Chapter 2 are tested and extended in Chapter 3. The experiments that are reported here employed successive field techniques to investigate both temporal integration and backward camouflage masking.

Chapter 4 argues that partial report and temporal integration results are not incompatible, particularly in

the light of the findings from the previous empirical chapters. Predictions generated in the introductory discussion are empirically tested in a partial report experiment.

Chapter 5 provides a final summing up of the findings and conclusions from the empirical work. A model for visual processing of successive fields is presented and critically examined.

CHAPTER 2: TEMPORAL INFLUENCES ON SUCCESSIVE FIELD INTEGRATION

2.1 Introduction

As noted in Chapter 1, Coltheart (1980a, b) suggested that there were several forms of visual persistence. Partial report procedures were held to highlight *information* persistence, the attributes of which were a slightly positive (but sometimes nil) relationship with stimulus energy and little or no effect of stimulus duration *per se*. On the other hand, direct methods, such as those employed in temporal integration techniques, involve mainly *visible* persistence. The duration of visible persistence may be inversely related to stimulus duration and energy. Coltheart was presumably unaware, at the time of writing, of Di Lollo and Woods (1981) results that apparently divorced stimulus energy from duration.

Coltheart's distinction nevertheless provides a possible avenue for the resolution of the two opposing viewpoints outlined above. Most of the temporal integration evidence supplied by Di Lollo and his colleagues has demonstrated inverse duration and limited stimulus intensity effects with nonlexical stimuli. Where lexical operations were needed to recognise an integrated display, and thus provide an index of perceptual

integration[1], positive duration and positive stimulus intensity effects have sometimes been found. It is therefore possible that even within temporal integration techniques two different types of visual persistence can selectively operate. In the latter cases, there might be something about the nature of the stimuli that predisposes subjects to utilize information persistence. Visible persistence might only be useful when certain forms of pattern stimuli are used (e.g. those involved in missing dot tasks).

In view of the still uncertain effects of the above mentioned temporal parameters, it was considered that a worthwhile launching point for the empirical work of this thesis would be an exploratory investigation of the effects of these durations on temporal integration performance. Furthermore, it seemed important to study both lexical and nonlexical stimulus combinations. Accordingly, Section 2.1 of this Chapter concentrates on an exploration of the Eriksen and Collins technique where the combined stimuli form letter sequences. Section 2.2 considers various aspects of field duration where the integrated percept provided only nonlexical pattern information.

[1]Perceptual integration is the hypothetical process, or processes, that may underlie task performance.

Experiment 1: Temporal integration of letter parts.

Introduction

This experiment is a partial replication of the integration technique developed by Eriksen and Collins (1967). Perceptual integration was measured by the number of letters that could be reported from a combined display containing a four letter word. This was formed by the successive presentation of two individually unidentifiable but complementary stimuli (hereafter called stimulus subunits). Stimuli were light on dark and the ISI period was dark. This display was expected to obviate the problems of spatially overlapping fields.

Three temporal parameters (i.e. 1st field duration (Sd1), ISI and the 2nd field duration (Sd2)) were varied but stimulus intensity was constant. The test of the two opposing viewpoints, discussed in the introduction to this chapter, would be primarily how performance varied with Sd1. Stimulus intensity was constant so that any increase in Sd1 would increase the energy content (and hence the apparent brightness) of the first stimulus (S1) due to the operation of Bloch's Law (see Chapter 1). Presumably if a persistence trace was energy dependent then integration performance would show a positive relationship to this factor as well as a negative function for ISI. Since the energy content of S2 would also increase with duration, Sd2 would be important insofar as the apparent contrast between S1 and the stimulus in the following field (S2) might affect performance. On the other hand, visual persistence that decayed as a function of

SOA and was independent of stimulus energy would show deterioration in performance as Sd1 and ISI increased.

Stimulus subunits were designed to appear to be visually word-like. It was thought that this might encourage subjects to rely on information persistence as opposed to visible persistence. This, in turn, might improve the probability of obtaining a positive effect for Sd1.

Aim

To explore the effects of the durations of the 1st field, ISI and following field on the temporal integration of letter parts.

Method

Each of the three temporal factors of Sd1, ISI and Sd2 were presented at three levels. The resulting 27 conditions were factorial combinations of the following durations:

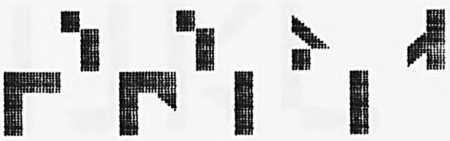
ISI : 33.33 , 50 and 66.67 ms.

Sd1 : 16.67 , 50 and 100 ms.

Sd2 : 16.67 , 50 and 100 ms.

The maximum combined stimulus duration (i.e. Sd1+ISI+Sd2) was therefore 266.67 ms (milliseconds) so that, in general, the incidence of involuntary eye movements should be low.

As mentioned above, the index of perceptual integration was the number of letters correctly reported in their correct locations from the collage display.



(A)



(B)



(C)

Figure 2.1 - Experiment 1: Stimulus designs
(a) This is an example of a complete subunit 1 stimulus. A four letter word is represented but the top left and bottom right quadrants of each letter have been blanked out.
(b) This is the subunit 2 complementary stimulus of the one depicted in (a). Here, each letter has its bottom left and top right quadrants blanked out.
(c) Image formed by the integration of (a) and (b).
N.B. The actual display was light on dark. Also note that the filter blur effect is not portrayed.

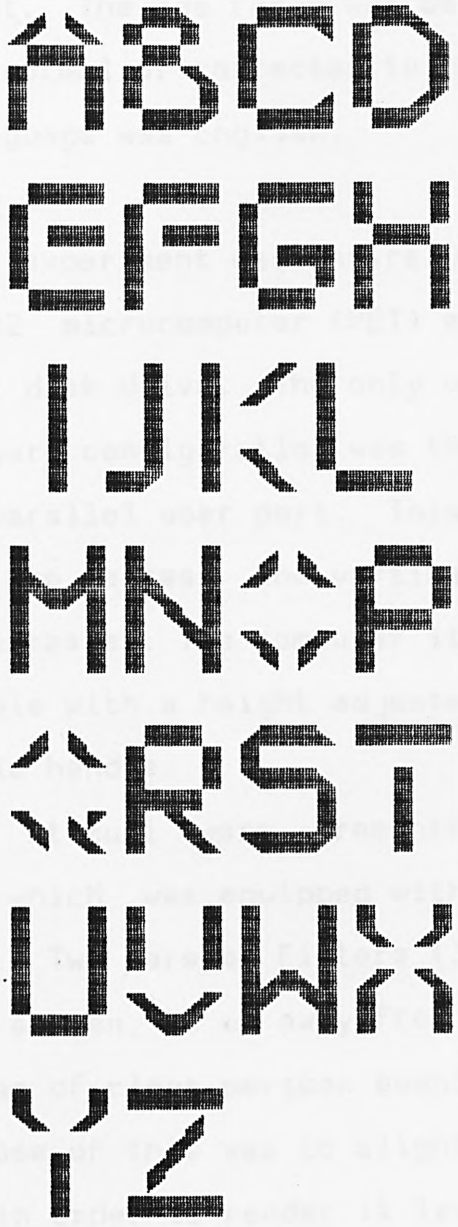


Figure 2.2 - Experiment 1: Illustrations of the complete designs of all the letters used in this experiment. In reality, of course, only the subunits of these letters were actually displayed.
N.B. The actual display was light on dark. Also note that the filter blur effect is not portrayed.

Subjects

Fifty-four subjects, drawn from first and second year undergraduate courses at The City University, took part in this experiment. Thirty-three of them were female. All of them were naive as to the purposes of the experiment. The age range was between 18 and 38 years. All had normal or corrected to normal vision and their first language was English.

Apparatus

The experiment was entirely controlled by a Commodore 3032 microcomputer (PET) attached to a Commodore 3040 dual disk drive. The only variation to the normal PET hardware configuration was the hardwiring of two pins on the parallel user port. This was done to enable the software to access the vertical pulse from the PET monitor's raster. The computer itself was positioned on a rigid table with a height adjustment facility operated by a lockable handle.

The stimuli were presented on the PET display monitor which was equipped with a medium decay green phosphor. Two perspex filters (3 mm thick) were fitted over the screen, 8 mm away from the surface. The first filter was of clear perspex evenly sanded on one surface. The purpose of this was to slightly diffuse the stimulus image, in order to render it less easily recognisable. The second was an amber filter. This acted in a similar way to a neutral density filter. It reduced the quantity of light output and thus lessened the visibility of any residual afterglow that might remain after the termination of a display. After passing through the screen fil-

ters, the resulting stimulus colour was pinkish white.

Ancillary equipment included an external microswitch wired to the parallel user port on the PET. This was the subject's trigger button that enabled him to instigate the start of a trial.

A dentist chair with an adjustable but rigid headrest was used as seating for the subject. Although bite boards are more usually employed in a visual experiment of this nature, the headrest, in this case, allowed adequate control of subject viewing positions and maximised their comfort.

Stimuli

One hundred and eight words out of an initial list of 654 four letter words (see Appendices 1 & 2) were selected to be experimental stimuli. All these words had been chosen from a directory of words that had been indexed for familiarity (i.e. word frequency) by Kuçera (1967). Three criteria for selection of experimental stimuli were adopted: (1) That letters were not repeated within a word; (2) the words were as far as possible neutral in emotive content, in the investigator's opinion; and (3) that the two subunits generated by each word gave minimum clues as to the identity of their constituent letters. On the latter point, the criterion for recognisability was that only one or no letters in a single subunit presentation could be identified. Moreover, the maximum sum of letters recognised after the separate and individual presentation of complementary stimulus subunits was 1 (out of a possible total of 8). The data for this had been obtained from a previous pilot

study that was designed for this specific purpose (see Appendix 1: Pilot 1).

The 108 experimental stimuli were randomly assigned to 9 pools, each containing 12 words. There was a constraint that each pool consisted of words with the following word frequency counts:

Number of words	frequency (words/million)
4	1- 9
2	10-19
1	20-29
2	30-39
3	>100

A further word pool containing 12 words was assembled for use in practice trials. These words were selected randomly from the remaining items in the original 654 word list without reference to letter recognition within subunits.

Stimulus design and display

The visual aspect of letters was constructed by using the PET's graphic character set. Each letter was designed on a matrix five small characters wide and six small characters high (each small character itself was built up from an 8x8 matrix of screen pixels). Curved edges were avoided in the design of letters so as to minimise the possibility of gaining clues about letter identification from a single stimulus subunit (the complete letter character designs are displayed in Figure 2.2).

The word subunits were designed by blanking out diagonal quadrants from each letter. Words with blanking in the top left and bottom right quadrants were designated as subunit 1 (Fig.2.1a). Similarly, the words with let-

ters blanked in the top right and bottom left quadrant were designated as subunit 2 (Fig.2.1b). Thus if subunit 1 and subunit 2 from the same word were to be aligned correctly and presented together, a word could be easily read (Fig.2.1c).

The maximum size of a letter was 27 mm high by 20 mm wide, whilst the minimum space between letters was 4 mm. The maximum width of a word subunit was therefore 92 mm.

Stimuli were displayed fairly centrally on the PET monitor, with the first letter character situated 20 mm from the left edge of the screen. In addition, prior to each stimulus presentation, a fixation stimulus (an asterisk 4 mm in diameter), located in the centre position of the composite stimulus, was briefly shown.

With filters in place the stimulus contours became slightly blurred so that the overall stimulus size was increased by approximately 1 mm per side. Thus, at the subject viewing distance (6 feet), the maximum horizontal visual angle for a complete stimulus was 2.94°. The maximum horizontal visual angle for a single letter was 0.69° and the vertical visual angle was 0.91°.

The stimulus luminance was measured by a Tektronix J6523-2, 1° Narrow Angle Luminance Probe, attached to a J16 digital photometer. When measured under experimental lighting conditions, mean stimulus luminance was 37 cd/m^2. The blank display yielded a mean luminance of 10 cd/m^2, due to reflected light.

Appendix 3 provides technical details about display characteristics.

Control of stimulus presentation and timing

All stimuli were timed by counting the number of display screen refreshes which occurred at the rate of 60 Hz. Hence, the smallest temporal resolution that was possible, with the present apparatus, was approximately 16.67 ms. For convenience, all timing details that are provided in this report have been converted to milliseconds.

See Appendix 3 for further technical details.

Procedure

The subjects were randomly assigned to one of three experimental groups, with the constraint that there were 7 males and 11 females in each. Each group was tested under all factorial combinations of Sd1 and Sd2 but ISI remained constant within groups.

The nine experimental word pools were presented in blocks of 12 trials each. The order of subunit presentation within trials was randomized but constrained so that within each block 6 trials began with subset 1. An extra block of 12 practice trials was presented at the start of each session.

Temporal conditions remained constant within all experimental blocks. The order of pool presentation was invariant for the first nine subjects in each group, the last nine subjects in a group experienced them in reverse order.

Condition blocks were randomised but constrained in a Latin square design for the first 9 subjects in each group. A similar design held for the last 9 but this time the condition order was reversed. Thus, a particular word

list (i.e. pool) and condition were only associated twice, once in the first nine subjects and once in the second nine. In this way, any response bias due to the order of word list presentation should have been minimized.

The experiment was conducted in a windowless room lighted by a single ordinary 40 watt bulb set in a hooded lamp stand. The stand was arranged so that all direct light was reflected off the ceiling. The mean luminance of the wall facing the subject,as measured from the subject viewing position, was 26 cd m^2.

Prior to the start of each session the seat headrest was adjusted for the subject's comfort. The height of the monitor was adjusted to be level with the subject's eyes. During this process, care was taken to ensure that a viewing distance of six feet was maintained.

The verbal instructions given to the subject were as follows:

> "As soon as you press your trigger button, a small dot will appear briefly on the screen followed by a very short blank period. Following this, a four letter word will appear on the screen. You may find that this word is difficult to read. Your task is to report what letters you saw and what their relative positions were. If you think that you recognise the word then spell it anyway. For example, if you see 'lark' then your response should be :- 'lark - L-A-R-K'. If you don't see the word but you recognise one letter then your response would be :- 'blank-blank-R-blank'.
> When the spot appears on the screen, fixate your eyes on it. They should be focusing there when the word appears but do not strain yourself in order to maintain this gaze, an approximate fixation is sufficient.
> After a block of twelve trials, the computer will become unresponsive for about 15 seconds, as it loads more words from the disk.
> It is important for you to keep your head firmly seated in the headrest for the duration of each

trial.
The first twelve trials are for practice purposes only. Queries may be answered after you have completed those trials.
Are there any questions about the instructions?"

Most of the subjects understood the instructions or reserved their queries for after the practice block.

All trials proceeded thus :

When the subject pressed the trial trigger button the central fixation stimulus appeared for 500 ms (the asterisk looked like a blurred spot at the subject viewing distance, due to the filters over the screen). Following this, the display was blank for a further 500 ms. Then either subunit 1 or 2 would appear for the predetermined duration followed by a blank interval whose duration had been set at the start of the session. This was then followed by a presentation of the complementary subunit for a prespecified duration, followed by a blank screen. The subject then gave his response which was written down by the experimenter (E). On practice trials, E provided verbal feedback and supplied the correct answer if necessary. Feedback was withdrawn for experimental trials.

At the end of the practice block, a further opportunity was given to the subject to ask questions but this option was rarely taken up. The subject was then informed that no more feedback would be given and told to proceed with the session at his or her own pace.

Temporal conditions did vary within the practice block. This was done so that each subject could obtain a preview of all the conditions that he or she would encounter during the session. The order of conditions in

all practice blocks was:

Trial	Sd1	Sd2	Trial	Sd1	Sd2	Trial	Sd1	Sd2
1	16.7	16.7	5	100.0	100.0	9	16.7	100.0
2	16.7	16.7	6	100.0	100.0	10	100.0	16.7
3	50.0	50.0	7	16.7	50.0	11	50.0	100.0
4	50.0	50.0	8	50.0	16.7	12	100.0	50.0

ISI's were set at the relevant experimental level. Subjects were only given verbal feedback by E during this (practice) block.

Results

Raw scores were converted to percentages of correct responses. Only letters reported in their correct positions were counted as correct. The mean scores are depicted in Table 2.2 and Figures 2.3, 2.4 and 2.5. The results of a 3 way ANOVA are shown on Table 2.1.

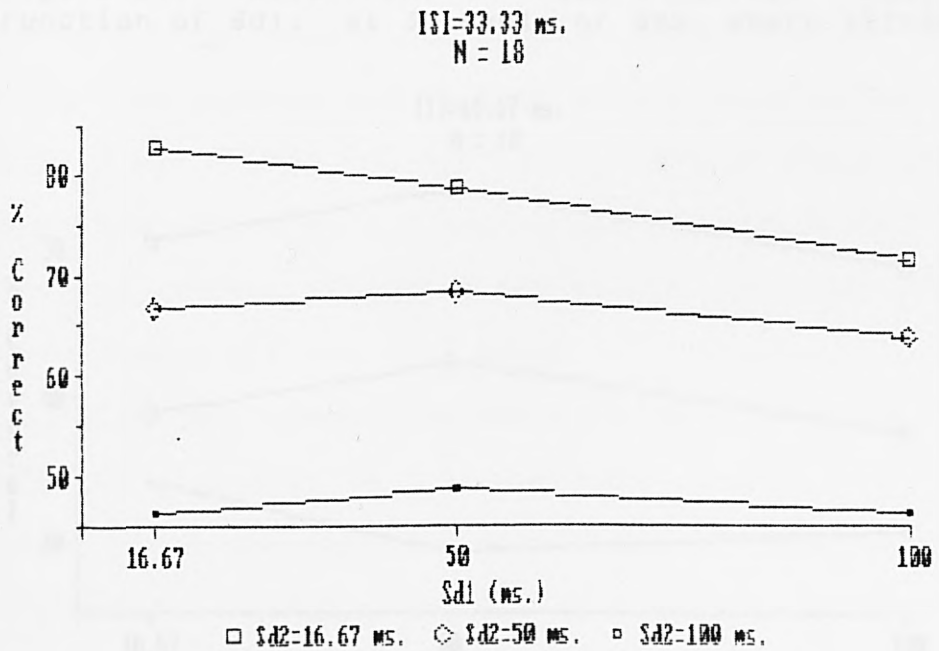


Figure 2.3 - Experiment 1: Mean % Correct scores as a function of Sd1, at 3 levels of Sd2, where ISI=33.33 ms.

There was a tendency towards an inverse relationship between the first subset duration (Sd1) and performance, which turned out to be highly significant (3 way ANOVA:

F=10.676; df=2, 102; p<.001). This effect is most evident where ISI is less than 66.7 ms (see Figs. 2.3 and 2.4).

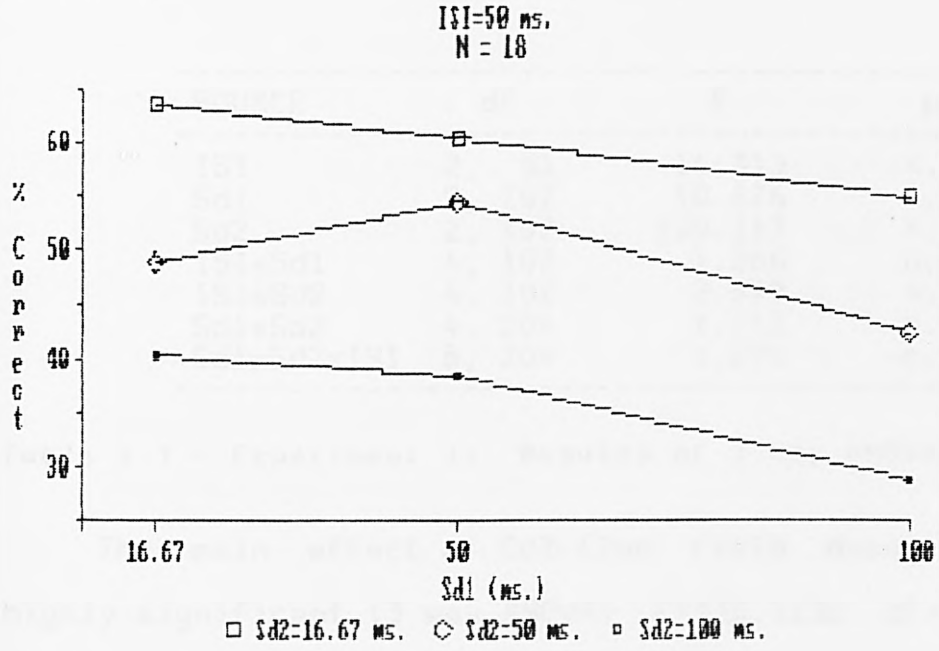


Figure 2.4 - Experiment 1: Mean % Correct scores as a function of Sd1, at 3 levels of Sd2, where ISI=50 ms.

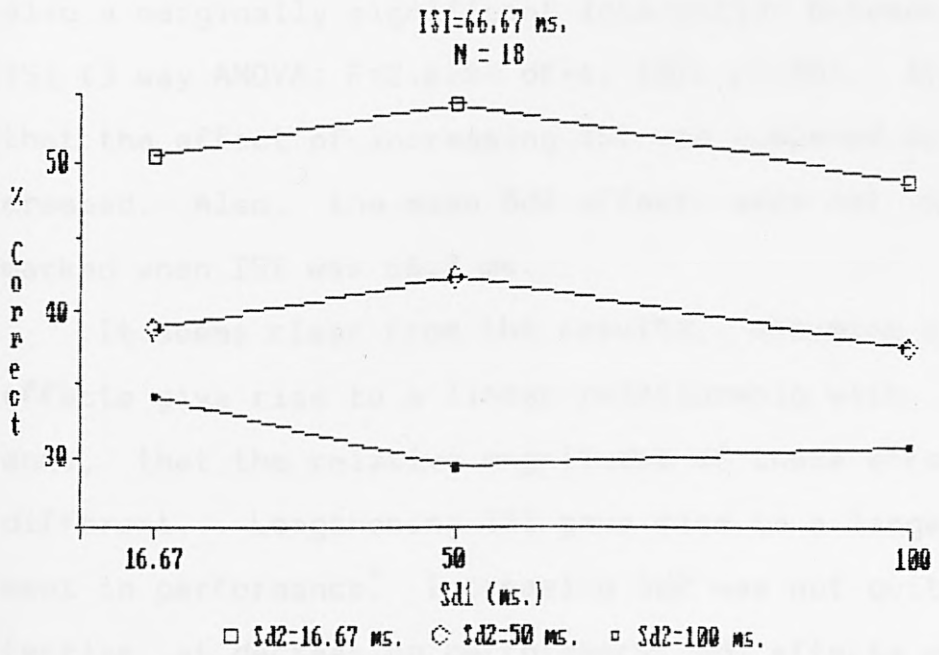


Figure 2.5 - Experiment 1: Mean % Correct scores as a function of Sd1, at 3 levels of Sd2, where ISI=66.67 ms.

A highly significant inverse relationship was found between ISI and performance (3 way ANOVA: F=14.313; df=2,

51; p<.001). Subjects in Group 3 (ISI=66.7 ms) had expressed a certain amount of psychological distress and reported that every trial was experienced as being very difficult.

SOURCE	df	F	p
ISI	2, 51	14.313	<.001
Sd1	2, 102	10.676	<.001
Sd2	2, 102	130.113	<.001
ISIxSd1	4, 102	1.266	n.s.[1]
ISIxSd2	4, 102	2.679	<.05
Sd1xSd2	4, 204	1.213	n.s.
Sd1xSd2xISI	8, 204	1.294	n.s.

Table 2.1 - Experiment 1: Results of 3 way ANOVA

The main effect of Sd2 (2nd field duration) was highly significant (3 way ANOVA: F=130.113; df=2, 102; p<.001). Thus, extending the duration of the 2nd field brought about severe decrements in performance. There was also a marginally significant interaction between Sd2 and ISI (3 way ANOVA: F=2.679; df=4, 102; p<.05). It appears that the effect of increasing ISI was dampened as Sd2 increased. Also, the mean Sd2 effects were not quite so marked when ISI was 66.7 ms.

It seems clear from the results, assuming all main effects give rise to a linear relationship with performance, that the relative magnitudes of these effects were different. Lengthening ISI gave rise to a large decrement in performance.[2] Increasing Sd2 was not quite as effective at decreasing performance[2]. Sd1 effects were not quite so clear cut, even though the main effect was significant in the direction of an inverse relationship with performance. The clearest inverse Sd1 effects occurred at

[1]not significant

[2]Statistical trend tests for linear analysis not included

the short and medium ISI's and at the short Sd2. The inverse duration effects were cumulative in the sense that performance was an inverse function of combined display duration (i.e. S1 onset to S2 offset).

Inspection of the graphs indicated an inverted *U* function as Sd1 increased. This was particularly evident at the 50 ms ISI level when Sd2 was 50 ms (see Fig. 2.4) and at the 100 ms ISI level when Sd2 was 16.67 and 50 ms (see Fig. 2.5). No sign of an inverted *U* performance curve was observed for changes in Sd2.

Many subjects reported, in an informal debriefing at the end of a session, that during difficult trials they saw two words in succession, but that they disappeared too quickly for them to be recognised. This was stated even by Group 1 subjects, who had undertaken the short ISI condition. Casual observation by the author, during pilot trials, revealed that the well integrated stimulus pairs, which were seen when all durations were short, appeared to become fused into a single image. However, when Sd2 was 100 ms then the two stimulus fields appeared as two distinct images. The interesting point here is that the latter phenomenon occurred even when Sd1 and ISI were very short.[1]

[1] Much of the ensuing empirical work was inspired by this observation. It appeared to the experimenter that instead of becoming perceptually integrated, as might have been expected when ISI was short, the successive fields were perceived separately.

Group 1 (N = 18)

Mean %	Std. Dev.	Sd1	Sd2	ISI
82.6386	7.1099	16.7	16.7	33.3
78.5879	10.9499	50.0	16.7	33.3
71.4124	14.8144	100.0	16.7	33.3
66.7825	14.6352	16.7	50.0	33.3
68.1714	15.3728	50.0	50.0	33.3
63.6576	18.5960	100.0	50.0	33.3
46.6435	18.1639	16.7	100.0	33.3
48.9099	17.9331	50.0	100.0	33.3
46.6435	19.5841	100.0	100.0	33.3

Group 2 (N = 18)

Mean %	Std. Dev.	Sd1	Sd2	ISI
63.4263	19.9855	16.7	16.7	50.0
60.3010	14.8261	50.0	16.7	50.0
55.0925	17.9672	100.0	16.7	50.0
48.7268	18.0086	16.7	50.0	50.0
54.2825	18.3924	50.0	50.0	50.0
42.2454	16.9222	100.0	50.0	50.0
40.3936	21.3673	16.7	100.0	50.0
38.4260	15.0100	50.0	100.0	50.0
28.7878	14.3023	100.0	100.0	50.0

Group 3 (N = 18)

Mean %	Std. Dev.	Sd1	Sd2	ISI
50.4629	19.2344	16.7	16.7	66.7
54.1668	18.7838	50.0	16.7	66.7
48.7267	18.9484	100.0	16.7	66.7
38.7732	13.9869	16.7	50.0	66.7
42.1297	21.4082	50.0	50.0	66.7
37.3842	13.1465	100.0	50.0	66.7
34.1750	20.5969	16.7	100.0	66.7
29.1669	17.3718	50.0	100.0	66.7
30.5556	19.2006	100.0	100.0	66.7

Table 2.2 - Experiment 1: Mean results (% Correct) on 27 conditions.

Discussion

The results give a clear indication that temporal integration performance was not positively related to stimulus energy. The marginally inverse but significant effect of Sd1 appears to support this.

The possibility that apparent contrast differences

between successive fields were detrimental to performance was considered. The rationale for this was described by Eriksen and Collins (1967, 1968). Their idea of temporal integration was perhaps based on the concept of a Type II persistence that is generated at stimulus offset (although, of course, Type I had yet to be postulated). A factor that might be expected to influence performance would be apparent brightness which would be dependent on stimulus intensity and duration (due to Bloch's Law). This factor might affect performance in two ways: (1) The brighter that each field was then the greater would be the perceived clarity of the stimulus would. This, in turn, might facilitate performance; and (2) it is possible that a perceived brightness contrast between successive fields could impair performance. Applied to the present experiment this predicts: (1) That performance should be positively related to stimulus duration; and (2) that the relative durations of S1 and S2 should also be important.

Tackling the latter prediction first, ideally the best performance would be obtained when S1 and S2 were of equal energy. However, since a decaying icon is indicated by the inverse ISI effect, the energy content in S1 would need to be slightly greater than that of S2 in order to compensate for this. Moreover, the energy differential in favour of S1 would have to increase as ISI increased and S2 energy remained constant. Alternatively, if S1 energy remained constant then S2 energy would need to decrease in order to maintain optimal (i.e. minimal) contrast. One prediction arising from this hypothesis is that the main effects of both Sd1 and Sd2 should evince an inverted *U*

function. The inverted *U* function relating to Sd1 would move to the right when ISI increased whilst the Sd2 function would gravitate left. Although the graphs indicated an inverted *U* function within the main effect of Sd1, it seems unlikely that this was caused by apparent contrast effects, for two reasons: (1) The apex of the Sd1 inverted *U* function was found, when Sd1 was 50 ms, in both the medium and long ISI conditions. There was no evidence of a shift to the right (it is possible that the variations in ISI may have been too small to elicit this shift). But also there was no significant evidence for the Sd1 x ISI interaction that might have been predicted from this; (2) there was absolutely no evidence of an inverted *U* function in the main effect of Sd2. It therefore seems reasonable to conclude that the apparent contrast between stimulus fields was not a major influence.

The predictions concerning the effects of stimulus duration on Type II persistence were not supported. On the contrary, it is clear that integration was a negative function of all the duration variables. The evidence is that each duration function was additive in its effect on performance (moderated by one marginal interaction). This brings the findings of the present experiment more in line with those obtained via other direct techniques and in particular with Di Lollo (1977, 1980). His hypothesis (two phase model: see page 85) was that stimulus duration rather than energy was the important variable in temporal integration tasks. As discussed in Chapter 1, he found that performance in a different type of temporal [pto]

integration task (missing dot) was inversely related to the leading field duration.

Although Di Lollo's general findings accord well with the results of the present experiment, his assertion that persistence duration should be measured from stimulus onset, is not easily accommodated. With this view integration performance would be inversely related to SOA and would be completely insensitive to the relative values of Sd1 and ISI. In the present experiment, the mix of these temporal variables *did* seem to be important. For example, consider those conditions where SOA was 83.33 ms. Table 2.3 lists scores (mean %) for pairs of conditions where Sd2 was constant and SOA was 83.3 ms. Note that performance was always better at the shorter ISI. Further support that the Sd1/ISI mix had an important influence on performance was suggested by the general observation that the slopes of the ISI functions were always greater than for the Sd1 functions.[1] Unfortunately, stimulus energy may have been confounded with stimulus duration so that these conclusions can only be tentative.

Mean %	Std. Dev.	Sd1	Sd2	ISI
78.5879	10.9499	50.0	16.7	33.3
50.4629	19.2344	16.7	16.7	66.7
68.1714	15.3728	50.0	50.0	33.3
38.7732	13.9869	16.7	50.0	66.7
48.9099	17.9331	50.0	100.0	33.3
34.1750	20.5969	16.7	100.0	66.7

Table 2.3 - Experiment 1: Mean % Correct scores (Mean % column) in conditions where SOA was approximately 83.3 ms.

[1] This observation was not statistically tested.

The inverse Sd2 effects were something of a problem. They do not appear to support the predictions of the contrast model discussed above and at the same time they do not fit into Di Lollo's two phase hypothesis. According to this latter model, as long as the energy of the following field enabled the subject a clear perception of the stimulus then the duration of the following stimulus should have little effect on integration performance.

Two broad categories of explanation for the inverse Sd2 influence need to be considered, as follows:

(1) The long Sd2 may have disrupted the processing of the first stimulus. For example, perhaps persistence was terminated too early for the collage to have become fully processed.

(2) Perceptual integration was inhibited by the long Sd2 but visual information from the first field was not entirely lost. The implication here is that visual information about S1 might remain somehow available even though it could not be utilized to integrate with S2.

Experiment 2 was an attempt to investigate the inverse Sd2 effect further in terms of the first approach. If that argument is correct then a word should be apparently backwardly masked by a following superposed stimulus. Furthermore, the extent of masking would be positively related to mask duration. An effect such as this might support the idea that the inverse Sd2 effect in Expt. 1 had more to do with disruptive rather than integrative processes. Miller (1970) was able to demonstrate backward masking of a green masking stimulus which superposed an identical red target. However, he found it

necessary to use very long duration targets (700 ms) which were beyond the temporal range that was used in Expt. 1.

In the following experiment, the potential backward mask was either a partially superposed stimulus (i.e. all mask contours were shared with the target but some target contours were not overlaid) or a bar mask overlay which produced incompatible target-mask contours and covered the whole target. It was thought that the latter type of following stimulus would be quite likely to induce backward masking effects. This condition would therefore provide an index of the degree to which 1st field identification could be impaired. As long as masking in the bar mask condition could be demonstrated, then a positive relationship between the superposition stimulus duration and masking might be evidence for the disruption of target or collage processing.

Experiment 2: Backward masking with overlapping inter-stimulus contours

Introduction

The presentation format in this experiment was similar to Expt.1. However this time a visually intact four letter word was presented as a target in the 1st stimulus field (S1). The index of masking was the number of letters correctly reported in their correct locations.

The partial superposition stimulus was a visual subunit of the S1 stimulus (see Expt. 1). The mask that presented incompatible contours was a series of vertical

bars that were spatially aligned to overlay the whole area of the previously presented target. The only temporal independent variable was S2 duration (Sd2).

It was mooted above that the inverse Sd2 effect (noted in Expt. 1), may have been due to the disruption of S1 or collage processing. If that was true then the probability of correct identification of the intact word should also be adversely affected by increasing Sd2, regardless of mask type.

The bar mask condition was included to ensure that identification performance could be disturbed at the experimental SOA. Since the bar mask, unlike the superposition mask, would be antagonistic to the contours of the S1 stimulus, it was expected that it would cause a relatively strong masking effect. Indeed a failure to obtain differences in performance due to S2 type might invalidate the experiment on the grounds that SOA was so long that any mask had little chance to influence performance.

Aim

To determine whether backward masking was inversely related to mask duration.

Method

There were two levels of following field duration. These were 50 and 100 ms. First field duration and ISI were constant at 33.3 and 50 ms respectively. The two levels of S2 type were factorially combined with Sd2 so that there were four experimental conditions in all. Subjects participated on a repeated measures basis.

The index of masking was the number of letters cor-

rectly reported in their correct positions.

Subjects

Six female and two male subjects were involved and were all naive as to the purposes of the experiment. They were all recruited from the 1st or 2nd year psychology undergraduate courses at The City University. The age range was between 18 and 36 years. All spoke English as a first language and all had normal or corrected to normal vision.

Stimuli

One hundred and four, 4 letter words were selected to be experimental stimuli from the original word pool of 654 words (see Expt 1 and Appendix 1). The criteria for selection remained the same as those applied in Expt. 1, although the rules for choosing words with unidentifiable subsets were slightly relaxed (see Appendix 1: Pilot 1). None of the stimuli had been used in the previous experiment. All of them were words whose frequencies were below 100 per million (as determined by Kuçera 1967).

The stimuli were assigned to 8 experimental word lists of thirteen words each. As far as possible, this was achieved randomly but care was taken to ensure that words with similar spelling (particularly first letter similarities or syllables) were well spread out between lists. Furthermore, each pool was to contain between 7 and 9 very low frequency words (less than 10 per 10^6 words). Two extra lists, containing 12 words each, were compiled in order to be used in practice trials.

Stimulus design and display

The visual characteristics of the words and subunits

have already been described in the previous experiment. The only difference was that S1 was actually a combination of subunit pairs. The dimensions of the intact word (Fig. 2.1c. see also Fig. 2.2) and subunit stimuli (Fig. 2.1a, b) were the same as those given in Expt. 1.

The bar mask was produced on the display monitor by generating 15 bars of inverse blanks over the same position as the previously presented word. Its visual aspect was somewhat similar to that produced by a square wave grating (see Figure 2.6). It was aligned on the monitor so that if a word and mask had been presented simultaneously, then the word would have been completely overlaid by the mask. The mask height was the same as the letters (27 mm). The bars were each 4 mm wide and separated by a gap of 4 mm, thus the total mask width was 116 mm.

With filters in place (see Expt.1) the visual aspect of the bar mask was something like a sine wave grating.

The visual angles subtended by word and subunit stimuli were as given previously in Expt. 1. The bars of the mask and the full mask gave rise to visual angles in the horizontal plane of approximately 0.16° and 3.63° respectively.

Stimulus luminance remained the same as for Expt. 1.

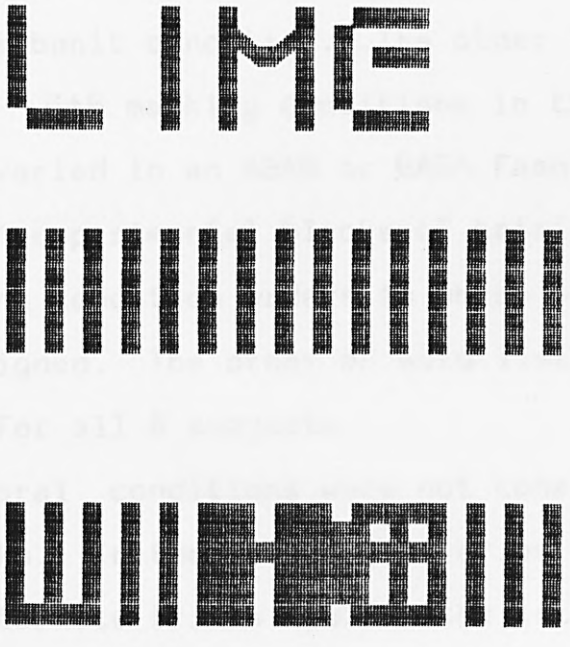


Figure 2.6 - Experiment 2: S2 bar stimulus overlaying the word *LIME* (these stimuli were displayed successively). N.B. The actual display was light on dark. Also note that the filter effect is not portrayed.

Procedure

All aspects of laboratory conditions and trial procedures remained the same as described for Expt. 1. Instructions to subjects were almost identical to those given in Expt. 1, except that reference was made to the fact that the experiment would be conducted in two parts (a short break occurred between the 4th and 5th blocks).

Each subject participated in 10 blocks of trials. The 1st and 5th of these were for practice purposes. Temporal and masking conditions were constant within experimental blocks. Experimental blocks each consisted of 13 trials and practice blocks contained 12 trials. One male and three female subjects received the bar mask condition in the first five blocks followed by five blocks with the subunit condition. The other four subjects were presented with masking conditions in the reverse order. Sd2 was varied in an ABAB or BABA fashion between each group of 4 experimental blocks of trials. Thus there were 8 different condition orders to which subjects were randomly assigned. The order of word list presentation was the same for all 8 subjects.

Temporal conditions were not constant within practice blocks. In these, Sd2 was varied between 50 and 100 ms on alternate trials (Sd2 on the 1st trial was always 50 ms). As before, it was only during these trials that subjects were provided with feedback.

On completion of the first five blocks in a session, the subject was given a short break. During this time he was informed about the change in S2 condition.

Results

Mean % Correct scores are given in Table 2.4 and depicted in Figure 2.7.

Table 2.5 gives the results of a 2 way ANOVA and from this it can be seen that only the main effect of the masking factor was significant. Thus the bar type was exerting a backward masking effect.

There was some evidence of an inverse Sd2 effect in the bar mask condition but this was virtually absent when S2 was a superposed stimulus.

Mean %	Std. Dev.	Sd2(ms)	Mask
82.925	10.6055	50	superposition
81.975	13.1327	100	superposition
70.675	18.0142	50	bar
66.225	19.9901	100	bar

Table 2.4 - Experiment 2: Mean % Correct scores. Sd1=33.33 ms; ISI=50 ms.

SOURCE	df	F	p
Sd2	1, 7	1.156	n.s.[1]
Mask	1, 7	13.304	<.01
Sd2xMask	1, 7	0.316	n.s.

Table 2.5 - Experiment 2: Results of 2 way ANOVA.

[1]not significant

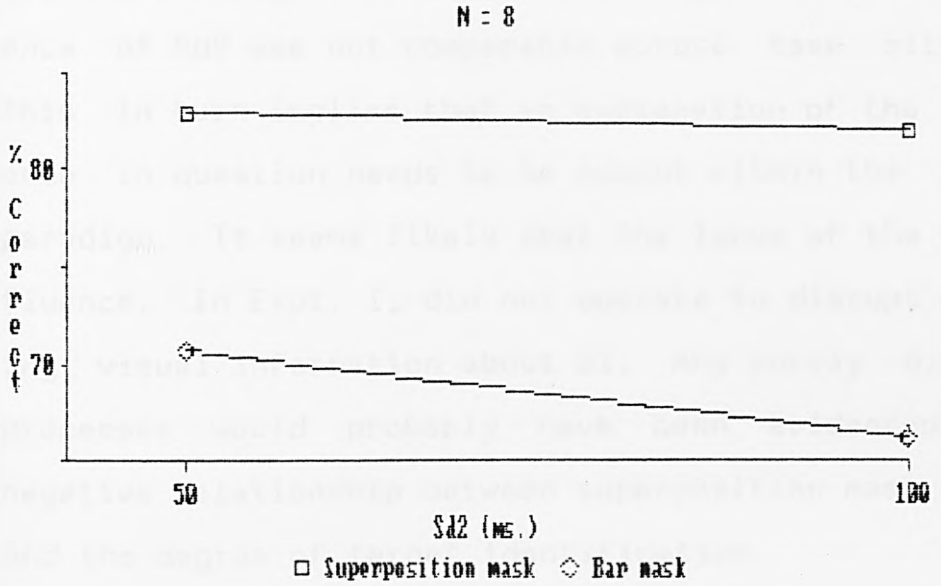


Figure 2.7 - Experiment 2: Mean % Correct scores as a function of Sd2. Sd1=33,33 ms; ISI=50 ms.

Discussion

The significant differences between the mask type conditions does indicate that the target stimulus was susceptible to masking at the SOA employed in this experiment. This does not necessarily imply that the subunit mask condition did not cause any masking effects. Nevertheless, there was no evidence to suggest that the duration of the superposition stimulus influenced the degree of masking.

The graphical evidence suggests that there was a positive masking effect with increases in bar mask duration but this was not supported by a significant interaction. It is nevertheless possible that some variation was caused by the higher energy of the longer duration mask.

The general results, when contrasted with the

strongly negative influence of Sd2 in the temporal integration paradigm (see Expt. 1), suggest that the influence of Sd2 was not comparable across task situations. This in turn implies that an explanation of the phenomenon in question needs to be sought within the original paradigm. It seems likely that the locus of the Sd2 influence, in Expt. 1, did not operate to disrupt persisting visual information about S1. Any purely disruptive processes would probably have been evidenced by a negative relationship between superposition mask duration and the degree of target identification.

2.2 Introduction

The experiments presented in the previous section reported four main findings in respect of successive field operations:

(1) Integration performance was inversely related to the leading stimulus duration.

(2) Integration performance was inversely related to ISI.

(3) Integration performance was inversely related to the following field duration.

(4) Backward masking with overlapping contours is either unrelated to mask duration or there may be a slightly positive relationship.

Unfortunately, because stimuli of different durations had not been energy equated, it was impossible to determine whether or not the duration effects were actually due to that factor. It could equally well be that integration performance was inversely related to stimulus

energy. In which case, the relevant independent variable might have been apparent brightness. This is thought to be proportional to stimulus energy where durations are less than about 100 ms (see Bloch's Law on page 18).

Di Lollo (1977, 1980), however, has shown that the inverse duration effect of the leading stimulus, in certain temporal integration tasks, occurred even when stimuli were energy equated. As discussed earlier, he used dot pattern fields that did not contain lexical information. It therefore seems reasonable to suppose that the inverse Sd1 and ISI effects found in Expt. 1 were at least partly due to a duration effect that was independent of apparent brightness. Moreover, the fact that no positive duration effects were noted indicates that there is no strength in the argument that temporal integration effects are dependent on the type of information inherent in a successive display (see introduction to this chapter).

No such assumptions can be applied to the inverse Sd2 effect which has yet to be independently implicated in the temporal integration literature (to the author's knowledge). Two immediate questions need to be answered in respect of this parameter on temporal integration:

(1) Can it be generalized to successive displays where the collage supplies nonlexical pattern information?

(2) Will the inverse relationship occur even when different duration stimuli are energy equated?

Experiment 3 was designed to address these problems. The temporal integration technique employed was the miss-

ing dot task similar to that developed by Hogben and Di Lollo (1974).

Experiment 3: Investigation of the Sd2 effect in a missing dot task

Introduction

Each of two successive fields was formed by projecting 12 dots at random to any of 25 spatial locations on the display. The resultant integrated image looked like a square 5x5 dot matrix with one dot missing. The index of perceptual integration was the probability of determining the spatial location of the missing dot. It seemed reasonable to suppose that if the two dot fields could not be perceptually integrated then the probability of correctly locating the missing dot would be virtually at chance level (Di Lollo, 1980 was able to achieve this level of performance).

First field duration (Sd1) and ISI were constant but the second field duration (Sd2) was varied between four levels. Stimulus energy was equated so that dots of all durations appeared to be of equal brightness. This was achieved by adjusting the light intensity of different duration dots.

All stimuli were formed by the projection of light dots on a dark background. The pre- and post-display fields were dark as was the blank ISI period.

Aims

To generalize the inverse Sd2 effect to the missing dot task and confirm that it was independent of variations in apparent brightness.

Method

Sd1 and ISI were constant at 10 ms each. Sd2 was varied over four levels of 50, 100, 150 and 200 ms.

Display intensity was adjusted so that all stimuli appeared to be presented at approximately the same brightness.

As mentioned above, the dependent variable was the probability of correctly locating the missing dot. A repeated measures design was used.

Subjects

The experimenter and four other subjects (2 male and 3 female in total), all of whom were staff in the Royal Free Hospital (London) employed in the Department of Psychological Medicine, took part in this experiment. All had normal or corrected to normal vision. Their ages ranged between 28 and 37 years. All, except the author, were naive about the purpose of the experiment. Three of them were reasonably well practised in the missing dot task.

Apparatus

Stimuli were presented on a Tektronix 604 A display scope, equipped with yellow-green medium-fast decay phosphor (P 31). A celluloid neutral density filter was inserted between the cathode tube surface and the normal clear perspex screen protector. Fitted in this way, the filter was held flat against the tube surface, thus

minimizing image distortion. Its purpose was to decrease, as far as possible, any residual screen phosphorescence that might have remained after stimulus offset. The display device was attached to a sturdy tripod via an adjustable swivel mechanism that could independently rotate in the vertical and horizontal planes. It was used to help standardize subject viewing distance and eye-screen angle.

The scope itself was driven via 3 input channels (X, Y and Z). The voltages of the X and Y channels defined the Cartesian coordinates of each dot and the voltage of the Z channel controlled the dot luminance. These voltages were controlled by a Commodore 3016 microcomputer (PET), equipped with a Commodore 3040 dual floppy disk drive. A purpose built multi-channel Digital to Analogue converter acted as an interface between the PET and the display scope (further technical details are discussed in Appendix 3).

A push button microswitch, encased in an empty 35 mm plastic film case, was attached via a long wire to the PET's parallel user port. This was to be used by the subject to initiate exposure presentations. A sturdy dentist chair, equipped with an adjustable headrest was used as a subject seat. The headrest was used to help standardize the subjects' viewing position. The subject viewing distance was determined with the aid of a metal tape measure.

Experimental control and timing

A stimulus was generated by successively projecting each dot to the twelve locations for about 10 μs. Each

refresh of twelve dots took 1 ms to complete, therefore stimulus durations were controlled merely by directing the system to complete the appropriate number of refresh scans.

Details of methods of obtaining luminance and timing calibrations are given in Appendix 3. However, it should be noted that the dot luminance values given in this report (as well as in those later experiments which used the same display device) were obtained by measuring the luminance of single dots from a distance of 710 mm. These values do *not* represent mean stimulus luminance but approximate conversions are given in Table A3.1 (see Appendix 3 for explanation).

Stimulus timing and intensity parameters were calibrated on a daily basis with the test procedures described in Appendix 3.

Stimuli and display

Each dot was approximately 1 mm in diameter. The distance between both horizontally and vertically adjacent matrix locations (dot centre to dot centre) was 20 mm, thus giving rise to a square matrix whose centre to centre dimensions were 80 X 80 mm.

The visual angle subtended by adjacent dot locations was 1.61° and the total matrix viewing angle was 6.53°.

Stimulus intensities were adjusted so that all dots appeared approximately as bright as if they had been presented for 100 ms at 0.057 cd/m² (see Appendix 1: Pilot 2). The 100, 150 and 200 ms stimuli could be presented at the same dot luminance without any brightness disparity becoming evident. The stimulus intensity adjustments were

tailored to individual subjects.

Prior to a trial sequence a central fixation dot was presented for 500 ms at 0.045 cd/m². The screen then remained blank for a further 500 ms before the onset of S1.

Procedure

Every subject took part in 5 sessions consisting of 110 trials each. The first session and the first ten trials in each of the following four experimental sessions were only used for practice purposes. Temporal conditions remained constant for all within session trials. The condition order was randomized for each subject.

The experimental apparatus was set up in a light-proof room with the subject seated on the dentist chair in front of the display scope. The experimenter station was about two metres behind this and completely shielded from S's view by a ten by seven foot high hardboard screen. The room was dimly lit by a heavily shielded 20 watt red lamp. There was just enough light for S to make out the outlines of the display so that he could orient his gaze. The reflected light from the blank display screen was 0.002 cd/m².

Subjects were trained to report via a system of coordinates; matrix columns were identified by the letters *A* to *E* (going from left to right) and rows by numbers *1* to *5* (top to bottom). Thus, for example, the top right dot location would be identified as *E1*. A forced choice method was chosen, subjects were asked to guess if they were not sure.

The viewing distance was 710 mm. Care was taken to ensure that the screen angle was perpendicular to the

subject's line of sight by adjusting the display angle until the S saw his eyes reflected centrally on the blank screen in both vertical and horizontal dimensions.

Trials proceeded as follows: Immediately after S initiated the trial sequence, a central warning dot appeared for half a second. The screen went blank for a further half second and then S1 appeared for 10 ms. The screen blanked again for 10 ms followed by S2 which was presented for a duration of 50, 100, 150 or 200 ms, depending on the predesignated session condition. The subject then gave his response which E typed into the PET. If the trial was for practice purposes then E provided verbal feedback which, if necessary, included the correct response. A new matrix was automatically set up by the system, to await S's next trigger response.

First stimulus (S1) patterns were randomly presented but only one dot in the 2nd stimulus (S2) pattern had any freedom of movement. The missing dot target locations were random but constrained so that every possible dot location was a missing dot target four times over the last 100 trials in a session. This was further constrained so that two of these possibilities were taken up in the final 50 trials.

The temporal conditions in the practice session were 10, 2 and 10 ms for Sd1, ISI and Sd2 respectively. Temporal integration performance was good under these conditions and the main purpose of these sessions was to familiarise S's with the display pattern and to provide them with practice in the reporting technique. This process also enabled E to vet subjects.

Subjects were given just one minute to adapt to the darkened laboratory lighting conditions prior to the start of a session. During this period, S's were reminded to orient their eyes towards the warning stimulus so that they would be looking roughly at that location at flash 1 onset. They were also strongly reminded to keep their heads firmly placed in the headrest for the duration of each trial. Thereafter subjects initiated each trial themselves.

Each session lasted approximately thirteen minutes. A subject participated in only one session per day.

Results

Mean results are given in Table 2.6 and graphs of individual % Correct scores are shown in Figure 2.8. The mean number of S1 dot locations which were mistakenly identified as the missing dot, expressed as a percentage of total error (% 1st Error), are shown for individual subjects in Figure 2.9.

% Correct	Std. Dev.	% 1st Error	Std. Dev.	Sd2
89.4	7.0922	65.76	24.7428	50
79.8	6.5345	79.14	12.4564	100
60.6	15.4532	86.58	6.1210	150
32.4	13.2401	86.82	8.7096	200

Table 2.6 - Experiment 3: Mean scores. % 1st Error is the mean number of S1 dot locations which were mistakenly identified as the missing dot, expressed as a percentage of total error.

Performance was clearly inversely related to Sd2 and this result was shown, in a 1 way ANOVA, to be highly significant (see Table 2.7). Four of the subjects showed a monotonic decline in performance as Sd2 increased. LMG

did evince a slight performance increase of 5%, between Sd2 values of 100 and 150 ms, but his performance fell substantially by almost 50% to 32% correct, between the 150 and 200 ms Sd2 levels.

The percentage of 1st Errors as a function of total Errors appeared to increase as Sd2 lengthened. However, a one way ANOVA that was computed on % 1st Error data was not significant (see Table 2.8).

SOURCE	df	F	p
Sd2	3, 12	32.8562	<.001
S's	4, 12	2.2745	n.s.

Table 2.7 - Experiment 3: Results of a 1 way ANOVA, where the dependent variable was % Correct score,

SOURCE	df	F	p
Sd2	3, 12	2.1233	n.s.
S's	4, 12	0.8345	n.s.

Table 2.8 - Experiment 3: Results of a 1 way ANOVA, where the dependent variable was % 1st Error score.

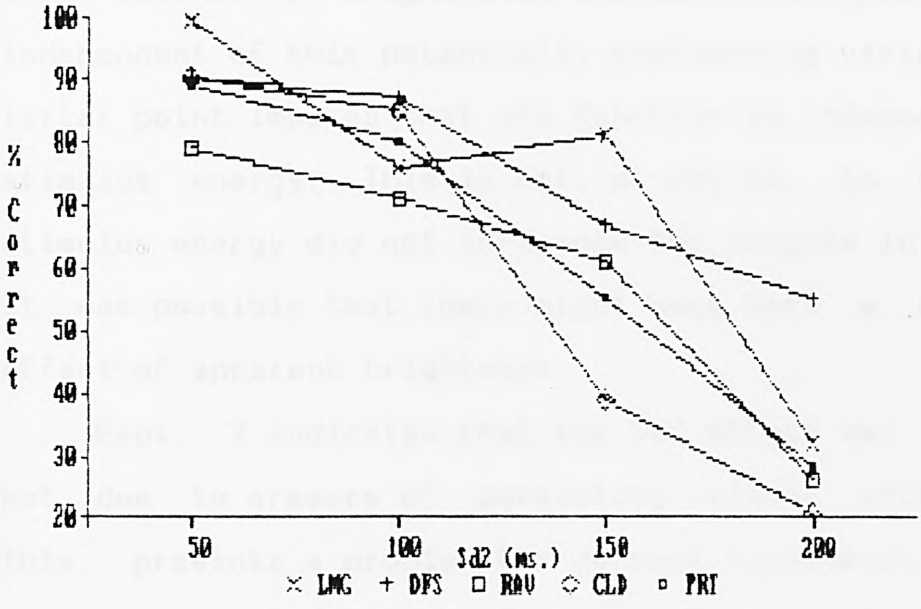


Figure 2.8 - Experiment 3: Individual % Correct scores, as a function of Sd2.

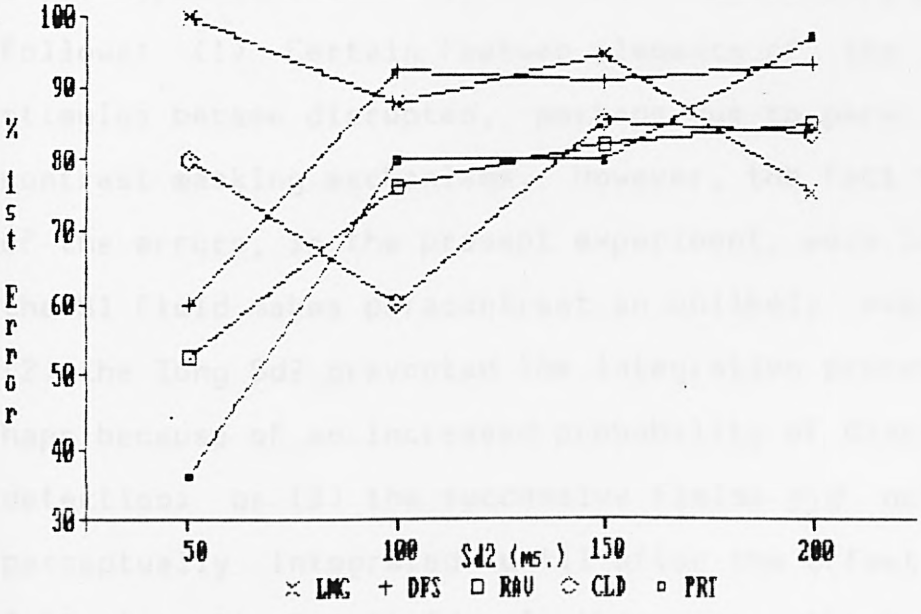


Figure 2.9 - Experiment 3: Individual % 1st Error scores, as a function of Sd2.

Discussion

The inverse Sd2 effect was confirmed in the present experiment, thus demonstrating that it could be general-

ized to the missing dot task. Moreover, since stimuli had been matched for brightness, the duration effects were independent of this potentially confounding variable. The latter point implies that its function is independent of stimulus energy. This is not, of course, to say that stimulus energy did not influence the results in Expt. 1. It was possible that there might have been a secondary effect of apparent brightness.

Expt. 2 indicated that the Sd2 effect was probably not due to erasure of persisting visual information. This presents a problem for current hypotheses which do not consider the role of the following stimulus (except insofar as S2 apparent brightness might influence the apparent contrast between successive fields). There are three hypotheses that may have some explanatory power, as follows: (1) Certain feature elements of the combined stimulus became disrupted, perhaps due to para- or metacontrast masking mechanisms. However, the fact that most of the errors, in the present experiment, were located in the S1 field makes paracontrast an unlikely explanation; (2) the long Sd2 prevented the integration process, perhaps because of an increased probability of discontinuity detection; or (3) the successive fields did not become perceptually integrated until after the offset of the following stimulus field. In this case, the inverse Sd2 effect might be a reflection of the length of time that the decaying persistence trace from S1 has to endure prior to perceptual integration. The apparent tendency for 1st field errors to increase with increases in Sd2 (although not significant) would support this idea.

Although the metacontrast hypothesis cannot be entirely ruled out, it does not present itself as a likely explanation, for two reasons. Firstly, the individual elements in the dot matrix display were separated by a reasonably large visual angle (1.61°). The large spatial separation between elements might have been expected to limit any metacontrast effects (see Breitmeyer, 1984; page 219) but in fact integration performance was strongly influenced by Sd2. Secondly, there is no general evidence to suggest that mask duration would affect the metacontrast function in the absence of mask energy fluctuations.

Discontinuity detection has been shown to play little part in missing dot tasks (Kinnucan and Friden, 1981). Moreover, the probability of discontinuity detection might be expected to increase as S2 intensity increases but in the present experiment performance declined as S2 intensity decreased.

The implication of the third hypothesis is that visual information about successive fields remained perceptually segregated until the termination of S2. This represents a somewhat radical departure from conventional hypotheses about temporal integration. Implicit in the arguments of conventional theories of passive integration is the notion that successive field integration will normally occur as long as information about both stimulus fields coexist in compatible visually coded form. Thus, these hypotheses might imply that perceptual integration will occur sometime shortly after S2 onset and that the duration of this stimulus field would be of little impor-

tance. Hence, there should be no inverse Sd2 effect as long as inter-field brightness was equated. On the other hand, the premise behind the idea of perceptual segregation is that information about both stimulus fields can coexist for a time without mutual interaction. In other words, the visual information about one field remains isolated from the other. Since the inverse effect of Sd2 on performance was monotonic it seems likely that perceptual segregation continued until the offset of S2 and it was only after this that a temporal integration process was initiated.

If this notion is correct then it is possible that the integration process may be triggered by some external event. The most obvious candidate for a trigger signal might be the operation of an offset detection mechanism responding to the abrupt termination of the following field stimulus.

If successive visual fields are indeed segregated in visual memory, then it would make sense to *tag* visual information elements by both onset and offset detection. In that way, feature elements could be identified as *new* (i.e. generated by ongoing stimulus activity) or *old* (i.e. memory traces with no current external correlates). Di Lollo and Bourassa (1983) may well have demonstrated the importance of the putative onset detection signal in missing dot tasks. They found that the poor temporal integration performance associated with a long Sd1 could be dramatically improved by raising the intensity of the last 10 ms of the S1 stimulus. It is possible that a new onset signal was generated by the sudden rise in stimulus

intensity. A similar effect was obtained when Di Lollo (1980) slightly displaced the spatial position of S1 dot elements over the last 10 ms of their presentation. In this case, the onset signal could have been provided by the late onset of the displaced feature elements.

The possibility of an offset detection trigger mechanism was investigated in the following experiment. A number of different independent variable manipulations were conducted but the main one was the inverse of the one employed by Di Lollo and Bourassa (1983). In one set of conditions, the intensity of the leading edge of the following stimulus (S2) was increased for various durations. Performance in this condition was compared with constant intensity S2 stimuli whose durations were the same as the total duration of the partially intensified S2 stimuli.

It was hypothesized that the sudden drop in intensity within the partly intensified stimulus would provide an earlier offset signal than in the constant luminance stimulus where offset could only occur at its termination. Thus, even though both conditions were presented at the same Sd2, integration might be facilitated by the former (intensification) manipulation. Certain other independent variables were included to investigate the effects of offset signal latency and to compare partially intensified and constant intensity stimuli.

Experiment 4: The effects of brief intensification on the leading edge of the following stimulus in a temporal integration task

Introduction

The index of perceptual integration was the probability of locating the missing dot in a 5x5 dot matrix. The design of the successive 12 dot fields (S1 and S2 respectively) was the same as described earlier for Expt. 3.

Sd1 and ISI and S1 intensity remained constant but S2 was manipulated in three different ways:

(1) In an experimental set of conditions (E.set), the overall Sd2 remained constant but the leading period of S2 was intensified for three different durations.

It was thought that the sudden drop in stimulus intensity within the S2 field in E.set conditions would induce an offset response before the final termination of S2. If this were so then performance might be expected to be inversely related to the duration of intensification. The reason for this is that the latency of the offset response should increase as this duration increases.

Normally, without intensity adjustments, the different levels of this condition would have given rise to differing sensations of S2 brightness. This was undesirable because apparent brightness and intensification duration would have become confounded. Fortunately, it was found that the two-tone nature of S2 could not be perceived at the experimental Sd2 (150 ms). The apparent brightness of S2 was therefore equated by adjusting the

luminance of the intensified part of S2. The intensity of the dimmer trailing edge of S2 was constant; it would have appeared to be approximately as bright as S1 if there had been no leading intensification. A diagrammatic representation of E.set conditions is shown in Figure 2.10.

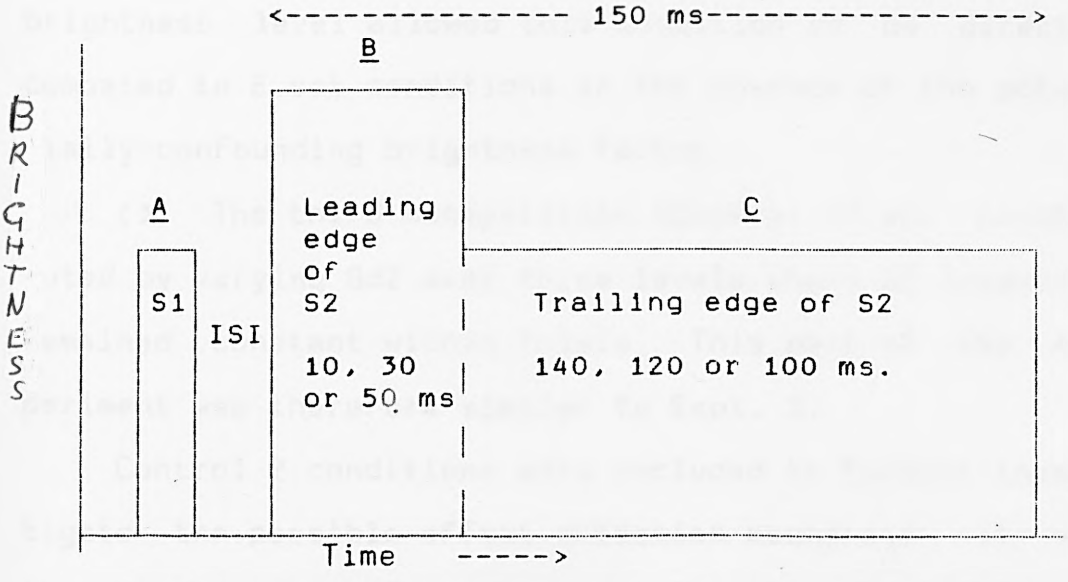


Figure 2.10 - Experiment 4: Diagrammatic representation of E.set displays. The apparent brightnesses of A and C were approximately equivalent. The summed brightness of S2 (B+C) was approximately equal across all three levels of E.set conditions. In order to achieve this, only the intensity of B was adjusted. The duration of B+C was constant at 150 ms. S1 and ISI durations were constant at 1 and 10 ms, respectively.

(2) The second manipulation (Control 1) allowed for control of the brightness properties of the E.set but without involving the intensification phase. Sd2 was the same as for E.set but S2 intensity remained constant within trials. Three levels of Control 1 were created by varying S2 intensity. At the highest level of intensity the S2 field was approximately the same brightness as the S2 field in E.set conditions. At the lowest level of in-

tensity S2 was approximately equal in brightness to S1. The medium level intensity produced an intermediate brightness sensation.

In these conditions an offset signal to S2 could only have been generated at its termination. It was therefore predicted that performance in all Control 1 conditions would be comparatively impoverished. The high brightness level allowed this condition to be directly compared to E.set conditions in the absence of the potentially confounding brightness factor.

(3) The third manipulation (Control 2) was constituted by varying Sd2 over three levels where S2 intensity remained constant within trials. This part of the experiment was therefore similar to Expt. 3.

Control 2 conditions were included to further investigate the possible offset detection mechanism. It was thought that the offset detection latencies in these conditions might be the same as those in E.set conditions. This seemed reasonable because the Sd2 values in Control 2 were the same as the intensification durations in E.set. It therefore seemed possible that these two sets of conditions (i.e. E.set and Control 2) might generate similar results.

An alternative hypotheses to be tested here is that integration is not sensitive to offset detection but is still somehow sensitive to Sd2. In this case it would be predicted that there would be no difference between E.set and Control 1 conditions.

Aims

The main aim of this experiment was to investigate

whether temporal integration performance would be facilitated by increasing the intensity of the leading edge of the following stimulus.

Two other aims were as follows: (1) to show that performance was inversely related to the duration of intensification; and (2) to test whether the effect of the intensified duration was equivalent to Sd2 without intensification.

Method

Subjects participated in all nine conditions. Sd1 and ISI were constant at 1 and 10 ms respectively. The dot luminance of S1 was always 4.36 cd/m².

The S2 parameters for each condition are presented in Table 2.9.

E.set:

	S2 Dot Luminance		Sd2
	Intensified (leading)	Normal (trailing)	
**	3.23 cd/m² (10 ms)	0.057 cd/m² (140 ms)	150 ms
**	1.28 " (30 ms)	0.057 " (120 ms)	150 "
**	0.83 " (50 ms)	0.057 " (100 ms)	150 "

Control 1:

	S2 Dot Luminance	Sd2
*	Low	0.057 cd/m²	150 ms
	Medium	0.154 "	150 "
**	High	0.429 "	150 "

Control 2:

	S2 Dot Luminance	Sd2
*	0.353 cd/m²	10 ms
*	0.167 "	30 "
*	0.123 "	50 "

* The apparent brightness of S1 and S2 stimuli was approximately equal in these conditions.

** The apparent brightness of S2 stimuli was approximately equivalent across these conditions. S2 appeared to be brighter than S1.

Table 2.9 - Experiment 4: Specification of S2 conditions.

Subjects

The experimenter and three other subjects, one of whom was female, took part in this experiment. All had normal or corrected to normal vision. They were employees in the Department of Psychiatry, at the Royal Free Hospital, London. Two of the subjects were well practised. Their ages ranged from 23 to 36 years.

Apparatus

All the apparatus was identical to that used in Expt. 3.

Stimuli

The stimulus characteristics were described previously (see Expt. 3). However, the display size was reduced by half so that the inter-dot spacing was now 10 mm (centre to centre: dot size remained the same). The corresponding visual angles between both horizontally and vertically adjacent dots and the combined display were approximately 0.81° and 3.31°, respectively.

A central fixation dot was presented for 500 ms at 0.045 cd/m^2, 1 second prior to the onset of S1.

The luminance data for E.set and the high intensity condition of Control 1 were derived from the mean results of Pilot 3 (see Appendix 1). The luminance data for Control 2 and the low luminance condition of Control 1 were derived from the mean results of Pilot 2 (see Appendix 1).

Procedure

The general procedural details remained identical to those described for Expt. 3.

Each subject took part in ten sessions, the first of

which was used for practice purposes (the same conditions prevailed as for the practice session in Expt 3). Stimulus conditions were constant within sessions and their presentation orders were randomized for each subject. Each session consisted of 110 trials with the first ten of these being used for practice purposes.

Missing dot target locations over the 100 experimental trials within a session were randomized in same way as described in Expt. 3

Results

Mean % correct scores are shown in Table 2.10 and are graphically depicted in Figure 2.11 (also see table 2.10 for *level* descriptions). Individual results are shown in Figures 2.12 to 2.15.

Poorest performance was obtained when Sd2 was 150 ms under nonintensified S2 conditions (Control 1). There was some graphical evidence that performance was further depressed in the high intensity condition. However, the results were shown not to be significant in a one way ANOVA that was computed for Control 1 data

($F_{Control\ 1}$=2.301; df=2, 6; not significant).

Performance was greatly improved by intensifying the leading part of S2 even though Sd2 was still 150 ms (E.set). This was apparent across all condition levels; the minimum difference between E.set and Control 1 data was 22.5 %. This occurred between the 50 ms intensification duration (E.set; level 3) and the low brightness condition of Control 1 (i.e. level 1).

Correct % Score	Std. Dev.	Within Set Level	Condition description	Name
76.75	17.5760	1	10 ms intensification	
67.75	15.1959	2	30 ms "	E.set
59.25	8.5391	3	50 ms "	
36.75	12.2031	1	Low S2 intensity	Control
35.75	15.8403	2	Medium S2 intensity	1
25.25	4.1130	3	High S2 intensity	
89.50	10.3441	1	Sd2 = 10 ms	Control
89.50	10.1489	2	Sd2 = 30 ms	2
88.50	8.6987	3	Sd2 = 50 ms	

Table 2.10 - Experiment 4: Mean % Correct scores.

There was evidence that performance was inversely related to intensification duration. These data were analysed in a Page's L trend test, since clear predictions were available, and they were shown to be significant (see Table 2.11).

Set	L	p
Experimental	54.0	significant
Control 2	50.5	not significant

N = 4, k = 3

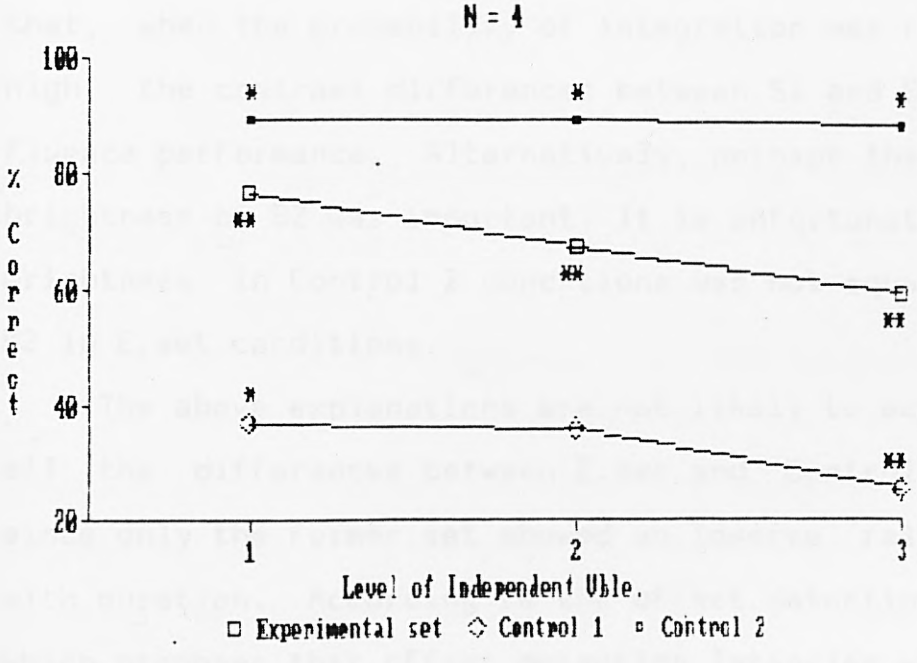
Critical value of $L_{\alpha=0.05}$ = 54

Table 2.11 - Experiment 4: Page's L Trend Test Results on E Set and Control 2

Best performance was obtained in the Control 2 conditions. All levels of this condition gave better performance than any of the E.set conditions. There was little evidence of the inverse Sd2 effect here and indeed a Page's L trend test showed that these results were not significant (see Table 2.11).

However, the failure to obtain the inverse Sd2 effect with Control 2 data need not be interpreted as a failure of replication. The low intensity condition in

Control 1 was an extension of Control 2 conditions in that it presented a long Sd2 (150 ms) where S1 and S2 were matched on brightness. This condition *did* result in a considerable performance deficit. It seems likely, therefore, that the absence of the effect for the 3 levels of Control 2 was due to the choice of Sd2 values; these were probably too short. In fact, earlier pilot studies (not reported) had failed to obtain the inverse effect where Sd2 ranged from 10 to 40 ms when SOA was very short (20 ms).



* The apparent brightnesses of S1 and S2 stimuli were approximately equal in these conditions.

** These S2 stimuli were approximately equated on the apparent brightness dimension. S2 appeared brighter than S1.

Figure 2.11 - Experiment 4: Graph of mean % Correct scores. See Table 2.10 for *level* descriptions.

Discussion

Although S2 brightness was confounded both within and between condition sets it seems likely that this

variable was not responsible for all the large differences between conditions. This is indicated by the fact that Control 1 performance was always poor regardless of S2 luminance. The probable explanation for the differences between E.set and Control 1 results is therefore that intensification did improve performance. Moreover, the fact that performance was inversely related to intensification duration can only reinforce this conclusion.

The reasons for the differences between E.set and Control 2 results are not so clear since brightness, intensification and Sd2 were all confounded. It may be that, when the probability of integration was relatively high, the contrast differences between S1 and S2 did influence performance. Alternatively, perhaps the absolute brightness of S2 was important. It is unfortunate that S2 brightness in Control 2 conditions was not equated with S2 in E.set conditions.

The above explanations are not likely to account for all the differences between E.set and Control 2 data since only the former set showed an inverse relationship with duration. According to the offset detection model, which proposes that offset detection latencies would have been similar for both condition sets, both sets of data should have evinced similar performance slopes. In fact, however, only the E.set did show a decline.

The explanation for this might lie in the way that E.set stimuli were designed. In order to maintain the same S2 brightness with increasing intensification duration, the intensity of the leading edge of S2 was reduced. Since the intensity of the trailing edge remained

constant, this meant that the commensurate intensity drop within S2 was decreasing as intensification duration increased. It is therefore feasible that the strength of the putative offset signal declined and this may have resulted in an increased latency of the detection response.

Conclusions

The results of this experiment have supported the notion that successive field integration can be triggered by the offset detection of the terminal field. This is reinforced by the tentative conclusion that the latency of offset detection might be influenced by the degree of the inducing drop in intensity within S2.

It is interesting to note that the detection response was effective even though it was probably subliminal; the intensity change within E.set was not noticed by observers (at 710 mm).

The effects of brightness were not entirely clear. It seems possible that the relative contrast between stimulus fields did not influence the probability of integration itself. It may be that even when inter-field contrast was high, the collage was still perceptually available in some conditions. However, the saliency of some elements may have been affected if they were apparently dimmer than other elements and this, in turn, may have contributed to some observed differences in performance. It is, on the other hand, interesting to note that performance was not greatly affected by S2 brightness in Control 1 conditions. This might be expected because if the probability of integration was already low due to the long Sd2, then changes in brightness would be less likely

to make much difference.

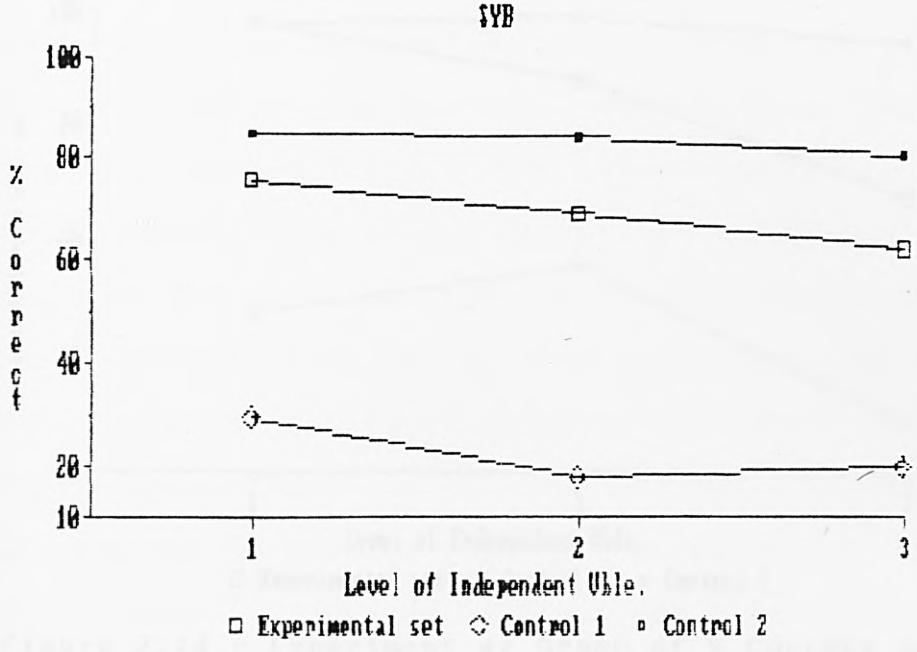


Figure 2.12 - Experiment 4: Graph of % Correct scores for subject SYB. See Table 2.10 for key.

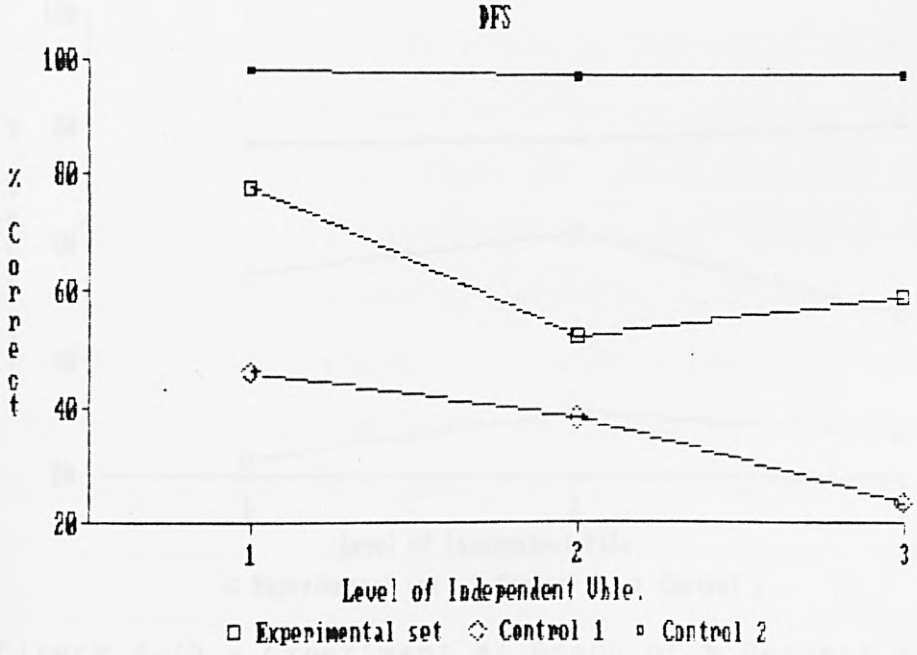


Figure 2.13 - Experiment 4: Graph of % Correct scores for subject DFS. See Table 2.10 for key.

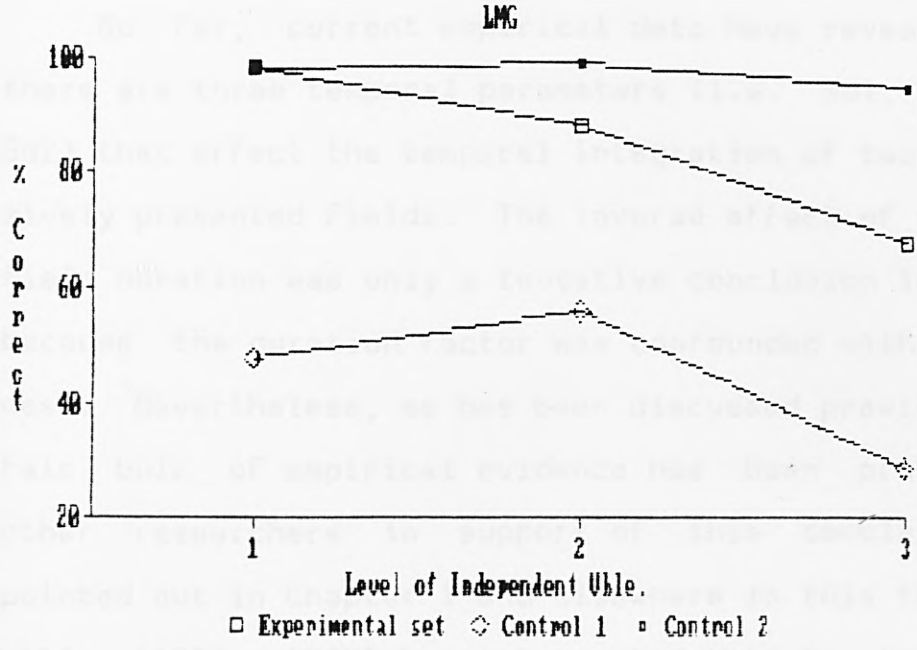


Figure 2.14 - Experiment 4: Graph of % Correct scores for subject LMG. See Table 2.10 for key.

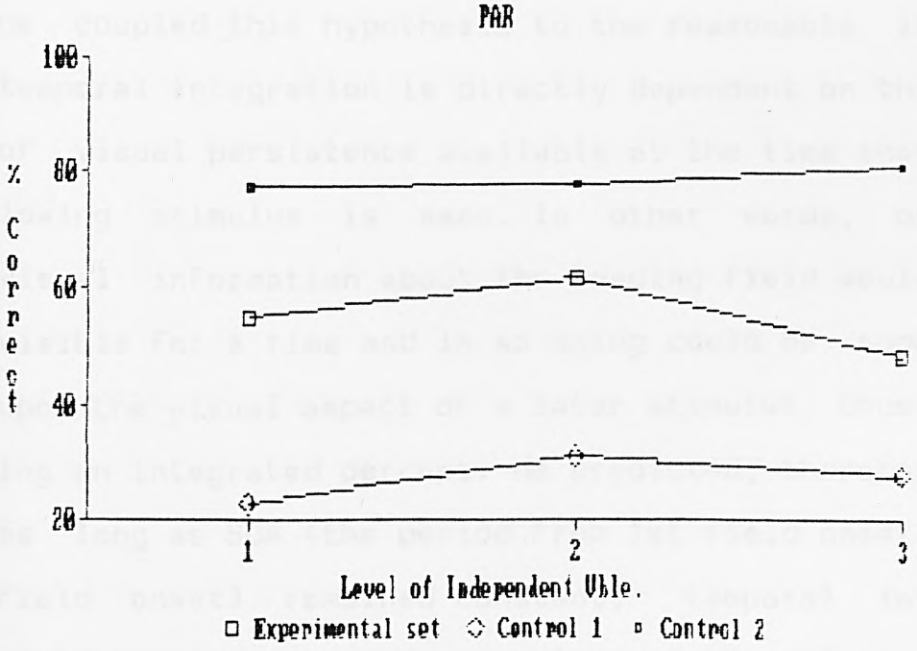


Figure 2.15 - Experiment 4: Graph of % Correct scores for subject PAR. See Table 2.10 for key.

Temporal Loci

So far, current empirical data have revealed that there are three temporal parameters (i.e. Sd1, ISI and Sd2) that affect the temporal integration of two successively presented fields. The inverse effect of the first field duration was only a tentative conclusion in Expt. 1 because the duration factor was confounded with brightness. Nevertheless, as has been discussed previously, a fair bulk of empirical evidence has been provided by other researchers in support of this conclusion. As pointed out in Chapter 1 and elsewhere in this thesis, Di Lollo (1977, 1980) has interpreted this to imply that persistence has a constant duration (at a given stimulus brightness) that should be measured from stimulus onset. He coupled this hypothesis to the reasonable idea that temporal integration is directly dependent on the degree of visual persistence available at the time that a following stimulus is seen. In other words, persisting visual information about the leading field would remain visible for a time and in so doing could be superimposed upon the visual aspect of a later stimulus, thus generating an integrated percept. He predicted, therefore, that as long as SOA (the period from 1st field onset to 2nd field onset) remained constant, temporal integration would remain unchanged regardless of the relative values of Sd1 and ISI.

With the introduction of yet another inverse duration effect (Sd2), it is possible that other higher order temporal influences underlie the results that have been presented in this thesis. For example, integration might

respond to total display duration (Td: the period from S1 onset to S2 offset) while the actual values of the component durations (Sd1, ISI and Sd2) might be irrelevant. Alternatively, the Sd2 effect might be indicative of a stimulus offset asynchrony effect (SOFFA: the period from S1 offset to S2 offset). In that case, with a constant Sd1 and SOFFA, integration would remain constant regardless of the absolute durations of ISI and S2.

Experiment 5 was an attempt to replicate the inverse Sd1, ISI and Sd2 effects. More particularly, however, emphasis was given to determining the relative functions of each of them. Although Expt. 1 had tentatively indicated that all three temporal functions were different (i.e. there was some evidence against higher order temporal relationships), stimulus brightness had been confounded with duration. In the following experiment, stimulus energy was equated so that the problem of confounding did not arise.

All three higher order durations were controlled so that even when they were constant, they contained different mixes of component durations. In this way it would be possible to determine whether there was any truth in Di Lollo's assertion about SOA and similarly, whether ISI and Sd2 effects were actually SOFFA effects. If the mix of component durations was irrelevant to both SOA and SOFFA then Td would be implicated as a prime determinant of integration performance.

Experiment 5: Temporal factors in visual integration

Introduction

The missing dot task was again used to index perceptual integration. Procedural details were similar to those described in Expts. 3 and 4 but, in the present design, all three temporal parameters (i.e. Sd1, ISI and Sd2) were varied. All stimuli were presented at approximately equivalent apparent brightnesses.

There were three possible durations for each of the stimulus duration variables. Thus, Sd1 and Sd2 could be either 10, 30 or 50 ms. ISI was varied across four durations of 15, 35, 55 or 75 ms.

These temporal components were combined in ten conditions which gave rise to hierarchical factors as follows:

(1) Two levels of Td (i.e. S1 onset to S2 offset). These were 75 and 95 ms.

(2) Two levels of SOA at 65 and 85 ms. In these conditions Sd2 was a constant 10 ms.

(3) Two levels of SOFFA at 65 and 85 ms. In these conditions Sd1 was constant at 10 ms.

This design, although not fully factorial, enabled a number of separate analyses to be performed with the aim of determining the relative functions of the component durations and whether they were evidence of higher order temporal relationships.

Aims

To replicate the inverse Sd1, ISI and Sd2 effects and determine the relative strength of each function.

To determine whether component duration effects were evidence of higher order temporal relationships.

Method

All the stimulus durations could take any of three values and the ISI varied between four durations. Certain Sd1 and Sd2 values were varied orthogonally around all but the 75 ms ISI. Ten conditions resulted from these combinations (see Table 2.12).

Condition No.		Sd1	ISI	Sd2	
Td=75 ms	1.	10 ms	55 ms	10 ms	*#
" "	2.	30 "	35 "	10 "	*
" "	3.	50 "	15 "	10 "	*
" "	4.	10 "	35 "	30 "	#
" "	5.	10 "	15 "	50 "	#
Td=95 ms	6.	10 ms	75 ms	10 ms	**##
" "	7.	30 "	55 "	10 "	**
" "	8.	50 "	35 "	10 "	**
" "	9.	10 "	55 "	30 "	##
" "	10.	10 "	35 "	50 "	##

* SOA=65 ms
** SOA=85 ms
# SOFFA=65 ms
SOFFA=85 ms

Table 2.12 - Experiment 5: Temporal conditions where Td is total display duration (i.e. S1 onset to S2 offset).

The conditions labelled * in Table 2.12 were to form the basis of a two factor analysis of variance where SOA was one factor (2 levels) and Sd1 the other (3 levels). In fact Sd1 and ISI were confounded but this was convenient because it enabled the SOA hypothesis to be evaluated. Similarly, those conditions labelled with '#' could indicate whether the absolute durations of ISI and Sd2 would influence performance with constant SOFFA (Sd2 and ISI were confounded). The Td hypothesis would be confirmed if the mix of component durations did not affect

both the SOA and SOFFA functions.

Subjects participated on a repeated measures basis (100 trials each per condition). They were all given practice prior to undertaking the experimental trials.

Subjects

Six subjects, including the author, took part in this experiment. They were recruited from staff and 2nd year medical students at the Royal Free Hospital, London. Three of them were female. Ages ranged between 20 and 36 years. All had normal or corrected to normal vision. All except two of them were highly practised at the missing dot task and all, except the author, were naive as to the aims of the experiment.

Stimuli

The shape and dimensions of stimuli were exactly as described in Expt. 4.

Stimulus duration	Dot Luminance
10 ms	0.353 cd/m²
30 "	0.167 "
50 "	0.123 "

Table 2.13 - Experiment 5: Dot luminance for different duration stimuli. All stimuli were brightness matched so that they all appeared at approximately the same brightness as a 100 ms stimulus presented at a dot luminance of 0.057 cd/m².

As mentioned above, the dot luminances were adjusted so that S1 and S2 appeared to be of approximately equal brightness. The mean results from Appendix 1: Pilot 2 were used as data for this, and the closest technically feasible luminances were presented (see Table 2.13). Dot intensity was therefore approximately equivalent to a stimulus projected at a dot luminance of 0.057 cd/m² for

100 ms.

Procedure

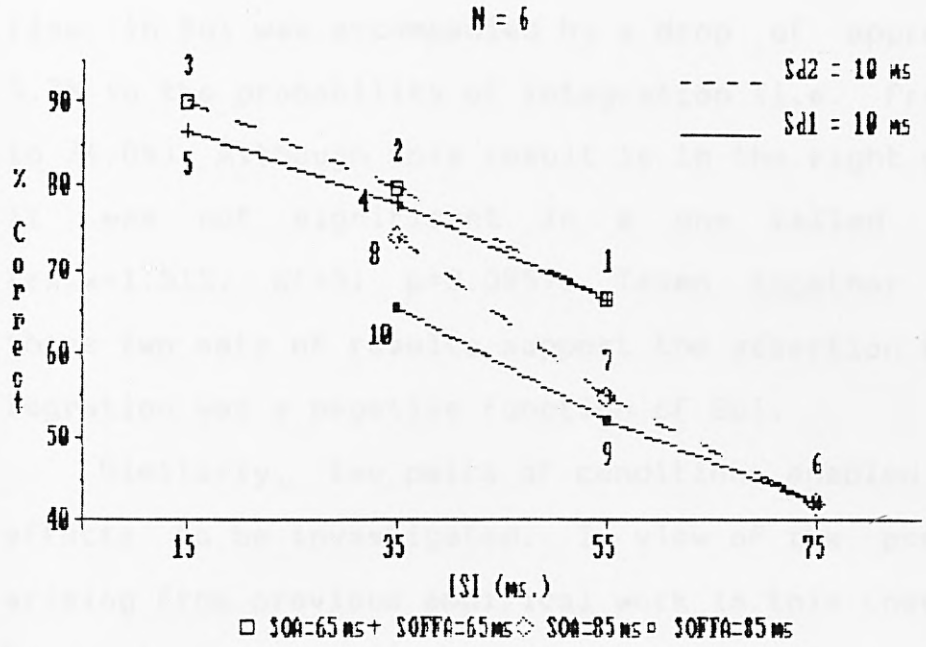
The general procedure in this experiment remained consistent with that described in Expts. 3 and 4. The arrangement of apparatus and laboratory lighting conditions also remained unchanged.

Each subject participated in 2 practice sessions and 10 experimental sessions. Each experimental session consisted of 100 experimental trials, preceded by 10 practice trials. Trial and stimulus randomization procedures remained exactly as previously described. All conditions remained constant within sessions but the order was randomized between subjects.

Practice sessions were completed before experimentation and consisted of 60 trials each. Sd1 and Sd2, in the first session, were 1 ms each and ISI was 2 ms. The second practice provided similar duration stimuli but ISI was increased to 55 ms. The latter condition was included to prepare subjects for the unusually long experimental ISI conditions.

Results and Discussion

Mean results are shown in Table 2.14, and are graphically depicted in Figure 2.16. As will be seen, all three component durations were inversely related to integration performance.



KEY:

No.	Sd1	ISI	Sd2
1.	10 ms	55 ms	10 ms
2.	30 "	35 "	10 "
3.	50 "	15 "	10 "
4.	10 "	35 "	30 "
5.	10 "	15 "	50 "
6.	10 "	75 "	10 "
7.	30 "	55 "	10 "
8.	50 "	35 "	10 "
9.	10 "	55 "	30 "
10.	10 "	35 "	50 "

Figure 2.16 - Experiment 5: Graph of mean % Correct scores. Each data point is marked with the relevant condition code.

Two pairs of data points were convenient for the evaluation of Sd1. The first pair were conditions 1 and 7 where Sd1 varied between 10 and 30 ms but ISI and Sd2 were constant at 55 and 10 ms respectively. Mean performance fell from 66.5% to approximately 54.7% correct as Sd1 increased by 20 ms. This result was shown to be significant in a one tailed *t* test (t_{1-7}=2.61; df=5; p=0.024). The second pair of data points were conditions 2 and 8, where Sd1 increased from 30 to 50 ms but ISI and

Sd2 were constant at 35 and 10 ms respectively. The 20 ms rise in Sd1 was accompanied by a drop of approximately 5.7% in the probability of integration (i.e. from 79.67% to 74.0%). Although this result is in the right direction it was not significant in a one tailed t test (t_{2-8}=1.515; df=5; p=0.095). Taken together however, these two sets of results support the assertion that integration was a negative function of Sd1.

Similarly, two pairs of conditions enabled the Sd2 effects to be investigated. In view of the predictions arising from previous empirical work in this thesis (see Expts. 1, 3 and 4), one tailed tests were used. The first pair to be considered consisted of conditions 1 and 9. Sd1 and ISI were constant at 10 and 55 ms respectively, whilst Sd2 increased from 10 to 30 ms. The commensurate drop in performance was 14.5% and this was computed to be highly significant in the t test (t_{1-9}=4.949; df=5; p=0.002). Increasing Sd2 from 30 ms (condition 4) to 50 ms (condition 10), where Sd1 and ISI were constant at 10 and 35 ms respectively, was associated with a 12.3% performance deficit and this result was also highly significant (t_{4-10}=4.603; df=5; p=0.003). These findings have therefore replicated the inverse Sd2 effect.

The ISI and SOA effects can be determined by considering one factor where SOA was 65 and 85 ms for each of the three levels of Sd1 and ISI mix (in conditions 1, 2 and 3 SOA was 65 ms [top dashed line in Fig. 2.16]; SOA was 85 ms in conditions 6, 7 and 8 [bottom dashed line in Fig. 2.16]). The 85 ms SOA condition was created by increasing ISI by 20 ms at each level of the 65 ms SOA con-

dition. Thus, the significant main effect of SOA (2 way ANOVA: F_{SOA}=23.178; df=1, 5; p<.01) also confirmed the inverse effect of ISI. However, the question was whether these differences were attributable to ISI *per se*, or to the change in SOA. It can be seen however from Fig. 2.16 that a constant SOA did not guarantee constant performance. The effect of the Sd1-ISI mix was given by the 2nd factor (nominally 3 conditions where Sd1 was 10, 30 and 50 ms). The main effect of this factor was highly significant (2 way ANOVA: F_{Sd1}=17.213; df=2, 10; p<.001), thus indicating that SOA was *not* the prime predictor of performance. No significant interactions were noted.

The above analysis revealed that Sd1 function must be a prime predictor of performance because it could not be explained in terms of SOA effects. However, the ISI effects that were noted above may have been due to changes in SOFFA because this latter factor was not controlled in the above considered conditions. SOFFA was controlled in the 6 other conditions which, by similar logic, gave rise to one SOFFA factor (2 levels at 65 and 85 ms) and one nominal Sd2 factor (10, 30 and 50 ms) where the effects of the mix of ISI and Sd2 could be investigated (in conditions 1, 4 and 5 SOFFA was 65 ms [top solid line in Fig. 2.16]; SOFFA was 85 ms in conditions 6, 9 and 10 [bottom solid line in Fig. 2.16]). The 85 ms SOFFA conditions were formed by increasing ISI by 20 ms at each level of the 65 ms SOFFA conditions. The main effects of both the SOFFA (and hence ISI) and nominal Sd2 factors were highly significant (2 way ANOVA: F_{SOFFA}=43.599; df=1, 5; p<.01: F_{Sd2}=22.771; df=2, 10;

$p<.001$) and there were no significant interactions. The latter main effect indicates that SOFFA could be eliminated as a prime predictor of performance but the significant effect of SOFFA shows that increases in ISI still exerted a deleterious effect on integration.

The above analyses have indicated that integration was inversely related to all three component durations and that these effects were *not* indications of higher order temporal relationships.

It was also of interest to investigate their relative effects:

Relative contributions of component durations: The ISI variations clearly exerted a stronger negative influence than either Sd1 or Sd2. This is illustrated in Figure 2.16 where at any of the 2 values for SOA or SOFFA the performance slope is negative. Consider, for example, the three conditions where SOA was 65 ms (top dashed line in Fig. 2.16). This represents conditions where Sd1 was decreasing by 20 ms (Sd1=50, 30 and 10 ms) at the same time as ISI was increasing by 20 ms (ISI=15, 35 and 55 ms). The slope is negative as ISI increases. This means that even though the ISI and Sd1 variations probably opposed each other, the negative pull of the increasing ISI was stronger than the positive pull of the decreasing Sd1. A similar situation occurred when SOA was 85 ms (bottom dashed line in Fig. 2.16). Both sets of negative slopes were shown to be significant in the two way ANOVA on SOA (see above: the relevant significant main effect was the nominal Sd1 factor).

The relationship between ISI and Sd2 was similarly

examined by considering conditions where SOFFA was constant (solid lines in Fig. 2.16). This time the negative pull of the increasing ISI is matched against the positive pull of the decreasing Sd2. Again the negative pull is stronger since both slopes are negative. The significance of the negative slope was confirmed in the 2 way ANOVA that was computed for SOFFA (see above: the relevant significant main effect was the nominal Sd2 factor).

The relationship between Sd1 and Sd2 was determined by considering the orthogonal variations between Sd1 and Sd2 at any particular ISI (Fig. 2.16: top dashed vs top solid lines and bottom dashed vs bottom solid lines). These show that performance was worse when Sd2 varied from 10 to 50 ms and Sd1 was 10 ms (solid lines) as opposed to when Sd1 varied from 10 to 50 ms and Sd2 was 10 ms (dashed lines). This suggests that the negative pull of Sd2 was stronger than the negative pull of Sd1. To confirm this, a 3 way ANOVA was calculated for all the data points except conditions 1 and 6. The three factors were: Total display duration (Td: 75 and 95 ms), Sd1:Sd2 (i.e. whether Sd1 or Sd2 was an independent variable) and the nominal Stimulus duration (Sd) factor (10, 30 or 50 ms: confounded with ISI). The Sd1:Sd2 factor was the main effect of interest here since this compared the orthogonal variations of Sd1 and Sd2. Moreover, the Td and the Sd factors had been investigated in the two 2 way ANOVA's that were reported on earlier. The results of the 3 way ANOVA computation are given in Table 2.15. It can be seen that all the main effects were significant but

without any significant interactions.

To summarize, all the inverse effects of the three component durations were replicated. There was no evidence to indicate that these effects were due to higher order temporal relationships. Each of the component duration functions therefore acted independently to influence integration. It is however possible that interactions, which could not be properly investigated in the present analyses (due to confounded conditions), might modify these findings. Nevertheless, the relative function of each component was shown to be different. ISI contributed most to integration variance, Sd2 contributed slightly less and Sd1, although still effective, exerted the weakest influence.

It is interesting to note that these findings accord well with the tentative conclusions that were drawn from Expt. 1. Moreover, they are entirely commensurate with Di Lollo's (1980) data about the relationship between Sd1 and SOA (see page 64) but this must support the earlier assertion that his conclusions were unwarranted.

Code	% Correct	Std. Dev.	Sd1	ISI	Sd2
1	66.500	22.0341	10	55	10
2	79.667	12.2583	30	35	10
3	90.167	11.8054	50	15	10
4	77.833	17.5774	10	35	30
5	86.500	9.7929	10	15	50
6	42.000	22.0091	10	75	10
7	54.667	29.5342	30	55	10
8	74.000	16.6132	50	35	10
9	52.000	22.6009	10	55	30
10	65.500	23.1754	10	35	50

Table 2.14 - Experiment 5: Mean scores.

SOURCE	Df.	F	p
F1	1, 5	15.258	<0.025
F2	1, 5	9.065	<0.05
F3	1, 5	12.184	<0.025
F1xF2	1, 5	1.083	n.s.[1]
F1xF3	1, 5	2.341	n.s.
F2xF3	1, 5	2.137	n.s.
F1xF2xF3	1, 5	0.217	n.s.

F1: Factor 1 - Total duration.
F2: Factor 2 - Whether Sd1 or Sd2 is varying.
F3: Factor 3 - Stimulus duration (nominal).

Table 2.15 - Experiment 5: Results of 3 way ANOVA.
N.B. Conditions 1 and 6 were excluded from this analysis.

Conclusions

Three main conclusions arose out of this experiment: (1) All three component temporal durations (i.e. Sd1, ISI and Sd2) were inversely related to integration when brightness was held constant.

(2) The effects of the component durations in the successive field task did not support the concept of higher order temporal relationships. In other words, there was no evidence that integration performance was fundamentally dependent on SOA, SOFFA or the total display duration.

(3) ISI variations caused the strongest performance effects and Sd1 variations produced the weakest ones.

It must be concluded that Di Lollo (1980) was not necessarily correct in his assertion that persistence is generated at stimulus onset. It was quite clear that the mix of component durations was important and hence the integration process could be more complex than it was

[1] not significant

previously believed to be. It may be that persistence availability is not the only limiting factor and, if this is true, then it would be misleading to conceive it to be directly measured by the present technique.

This experiment has confirmed the tentative conclusions arising from Expt. 1, as well as replicating the inverse Sd2 found in Expts. 3 and 4. Di Lollo (1977, 1980) was replicated for the inverse Sd1 effect. The failure to obtain evidence for a fundamental inverse SOA relationship was entirely in accord with empirical evidence presented by Di Lollo (1980), even though he interpreted his results differently. The common finding that ISI is inversely related to temporal integration (e.g. Eriksen and Collins, 1967) was also replicated.

In confirming that Sd1 and ISI variations produce differential inverse effects, this experiment has created a problem for conventional theories of temporal integration. If persistence is the sole determinant of integration, then if, as some authors believe (e.g. Long, 1980), persistence is generated at stimulus offset (and therefore ought to be measured from stimulus offset), there should have been no inverse Sd1 effect. If, on the other hand, the availability of visual information begins to decline from stimulus onset (and therefore persistence duration is inversely related to stimulus duration: Di Lollo 1977, 1980) then the propensity for successive stimuli to become perceptually integrated should be dependent on SOA. Thus, integration performance should not have been influenced by the particular mix of Sd1 and ISI as long as SOA remained constant; there should have been

no functional difference between the inverse effects of Sd1 and ISI. In other words, temporal integration should have been constant within a constant SOA. Coltheart (1980a) suggested the following two solutions (in respect of the possibility that Sd1 and ISI performance functions were dissimilar:

> "The first is that persistence should be measured from stimulus offset, and that there is a decreasing negatively accelerated function relating stimulus duration to persistence duration. The second is that there are actually two persistences, one generated by stimulus onset and the other generated by stimulus offset; their durations are both independent of the stimulus duration, but the onset persistence is, on the average, longer lasting than the offset persistence. Either suggestion is consistent with Di Lollo's data. The view that persistence is of fixed duration and generated at stimulus onset is, however, not entirely consistent with his data."

Note that Coltheart has attempted to explain integration performance only in terms of persistence duration. There is, however, an alternative approach. Perhaps, as suggested above, temporal integration is not only limited by persistence duration. It was speculated earlier that the inverse Sd2 effect might indicate that the successive stimulus fields did not become integrated until the offset of the second stimulus field. This was supported in Expt. 4, where it was found that the integration process was probably triggered by an offset signal generated by the termination of S2 (2nd stimulus field). If visual information about two visual stimuli can coexist without integrating, then it is possible that some process, other than persistence decay, could also operate to inhibit integration.

It is possible that the different effects of the

three component durations (Sd1, ISI & Sd2) were caused by interactions between the two processes. It may be, for example, that the inverse effect of Sd1 on integration performance does not indicate that persistence duration is inversely related to Sd1. Perhaps persistence duration is constant from stimulus offset and the Sd1 effect simply reflects the operation of the other hypothetical process.

Summary

It was pointed out in Chapter 1 that there were two divergent viewpoints that related visual persistence to temporal integration. These were the following:

(1) Persistence is generated at stimulus offset and its strength (and hence duration) is positively related to stimulus energy. This predicted that there would be a positive relationship between stimulus energy and temporal integration but no effect of stimulus duration *per se* (i.e. there would be no effect of stimulus duration when stimuli were energy equated). The brightness of a following stimulus was important insofar as this affected the apparent contrast between the successive stimulus fields.

(2) Visual information begins to be lost after stimulus onset. Hence persistence duration will be inversely related to stimulus duration. There is either no effect or an inverse effect of stimulus energy. Thus, temporal integration performance is inversely related to SOA and this effect is reflected by the fact that increases in both Sd1 and ISI progressively inhibit it.

Evidence in support of both these hypotheses has been claimed.

It was suggested at the beginning of this chapter that these opposing findings might be explained by the different types of stimuli used in successive field integration experiments. Where the integrated percept provided lexical information then positive stimulus energy effects might be obtained. The inverse duration effects might be found where the integrated stimulus patterns did not include lexical information. Thus, Experiment 1 investigated the successive field integration paradigm where an integrated percept provided lexical information and where even the unidentifiable individual stimulus fields were visually word-like. Sd1, ISI and Sd2 were varied orthogonally. The evidence supported inverse duration effects on all three independent variables. ISI effects appeared to exert the strongest influence while Sd1 effects were apparently weakest. Conclusions about the inverse temporal effects were only tentative because stimulus intensity was not adjusted to maintain an energy equivalence between stimuli of different durations. However, the preponderance of inverse duration effects did negate the original stimulus type rationale (i.e. concerning lexical versus pattern-only information).

Experiment 2 used a backward masking paradigm to investigate the effect of mask duration where target and mask contours overlapped. Where mask contours were compatible with the target, masking was weak and there was no noticeable effect of mask duration. Where target-mask contours were incompatible, masking was stronger and there was some (nonsignificant) evidence of a positive mask duration effect. However, since masking was

extremely weak in the superposition condition, it was concluded that the inverse Sd2 effect was not evidence that a following stimulus had disrupted the processing of the leading stimulus in the earlier temporal integration experiment.

The inverse Sd2 effect was replicated for energy equated stimuli in Experiment 3. This time the missing dot task was used so that the integrated percept did not supply lexical information. There was some evidence (not significant) that failure in this task was associated with loss of visual information about the first stimulus field. It was proposed that this phenomenon might indicate that successively presented stimuli did not become perceptually integrated until the offset of the 2nd field.

In Experiment 4, the effect of momentarily raising the intensity of the leading period of the 2nd stimulus field was explored. It was demonstrated that integration was improved by this procedure compared to similar Sd2 conditions which lacked leading intensification. This was interpreted to be evidence of the importance of an offset signal to an integration trigger mechanism. It was tentatively suggested that the latency of the hypothetical offset signal was inversely related to the change in intensity at the interface between the leading edge of S2 and its dimmer trailing part.

The purpose of Experiment 5 was to investigate whether the component duration effects in temporal integration tasks were evidence of higher order temporal functions. It was shown that this was not the case. Each

temporal component acted independently and in an additive fashion, although both these assertions might (and probably would) be moderated by interactions if examined with a fully factorial design. The relative strengths of the component functions were explored. All three inverse component duration effects were replicated and it was shown that the ISI function produced the strongest effects whilst the Sd1 function was weakest. It was pointed out that these results accorded well with the tentative conclusions expressed in Expt. 1. It was speculated that the differential Sd1 and ISI functions might indicate that temporal integration depended on two processes. Only one of these processes might reflect the operation of persistence decay.

CHAPTER 3: TEMPORAL INTEGRATION AND PERCEPTUAL SEGREGATION

Introduction

The conclusions of the last chapter led to the tentative hypothesis that visual information, generated by successively presented stimuli, remains segregated in the nervous system prior to the triggering of a temporal integration response. The trigger was hypothesised to be a termination signal that was normally generated by the offset of a following field and some evidence for this was found for this in Expt. 4. It was suggested, at the conclusion of Chapter 2, that integration may be limited by two processes. The first of these (but not necessarily 1st in operational sequence) was a persistence trace that may well begin to lose visual information at, or soon after, stimulus offset. The second was another process (as yet unidentified) that may inhibit integration as a positive function of one or more of the various component display durations (Sd1, ISI and Sd2). If this tentative model is correct then any measurement of persistence duration that is based on the temporal integration technique could be spurious, because it may be impossible to isolate the effect of persistence duration in integration tasks

The present chapter seeks to investigate one important aspect of the developing model of temporal integra-

tion. This is the possibility that visual information, about two successively presented visual fields, can coexist in a precategorically coded format but remain, for a time, perceptually isolated from each other. Thus, in the same way that the scrambled pieces of a jigsaw puzzle do not give many clues as to the form of the whole picture, visual information about successive displays might coexist for a time, in short term visual memory, without providing an integrated, or fused, percept. The need, in the following experiment, was therefore to empirically demonstrate that integration could fail, even when visual persistence from both successive fields has not been lost.

Integration masking and perceptual segregation

The concept of temporal integration suggests that a pattern stimulus could be backwardly masked by a following but spatially nonoverlapping stimulus, if the resulting perceptual montage bore little resemblance to the initial target. In other words, this type of masking would hypothetically be caused by the target becoming camouflaged by the mask.

This kind of technique has often been employed to test ideas of *erasure* (where target information is held to be disrupted by the mask) versus *integration* (i.e. camouflage) masking (e.g. Schultz and Eriksen, 1977; Navon and Purcell, 1981). The question of whether or not integration is a sufficient explanation for all types of masking is not of interest here (but see Expt. 2). However, as will be seen, the technique of integration mask-

ing may be useful in testing ideas about perceptual segregation.

If a target could be rendered totally indecipherable by a superimposed (and preferably spatially non-overlapping) noise mask, then the extent to which masking occurs in successive presentation will depend on target duration and ISI. The truth of the target duration and ISI predictions can be seen via a simple thought experiment: The more time there was available to process the target without interference from the mask, then the more chance there would be of identifying it (the above mentioned investigations have empirically demonstrated the ISI function).

According to passive theories of integration, the duration of a mask would be irrelevant as long as its energy remains constant. This assertion assumes that after the target and mask have merged through integration they can no longer become perceptually disentangled. Moreover, since no mechanism for perceptual segregation is hypothesized by passive theories, perceptual fusion between target and mask might be expected to take place at some constant time after visual information from the mask begins to coexist with the target in the relevant neural pathways.

The alternative hypothesis favoured in this thesis is that the successive fields do not fuse whilst the mask is being displayed. This leads to the speculation that differential processing of the target could continue during the period of mask presentation. If this is true then target identification performance would be positively re-

lated to mask duration. The rationale behind this is that as mask duration increases so target information will have more time to be processed and, as pointed out above, the longer the target processing period, the greater the probability of target identification.

Experiment 6 investigated this by presenting a letter that could be completely masked by a following and spatially superimposed but nonoverlapping visual stimulus. In one condition an index of masking was obtained by requiring subjects to identify the target letter. An index of integration was also obtained for the same type of stimuli. This was achieved by the performance of a missing dot task that could only be successful if a montage was perceived. It was also necessary to include a third task to act as a control condition.

Experiment 6: A comparison of following field duration effects on temporal integration and backward masking with nonoverlaping contours

Introduction

The standard 5x5 missing dot matrix was used in this experiment (see Expts. 3, 4 and 5), except that the S1 dot pattern (1st field) was no longer random. Instead the dots formed the shape of any one of 10 letters with one dot element missing (hereafter called the *pseudo* missing dot). The dots in the complementary S2 (2nd field) stimulus filled all but one of the remaining locations (see Figure 3.1). The probability of the successive

fields becoming visually integrated was manipulated by varying Sd2, whilst Sd1 and ISI remained constant.

Three tasks were to be performed, one of them being to locate the random position of a *real* missing dot (see Expts. 3, 4 and 5). This provided a measure of temporal integration. In another task, subjects were required to identify the letter presented in S1. According to the concept of perceptual segregation which was discussed above, letter identification performance should improve as integration deteriorates. Thus, there ought to be a positive relationship between letter identification and Sd2.

If, however, the inverse Sd2 effect found in the earlier reported experiments was not due to perceptual segregation then letter identification performance would not be sensitive to Sd2 (mask duration). Indeed, it might be the Sd2 effect was evidence that S1 persistence was becoming disrupted, in which case performance would be inversely related to mask duration.

Because there were only ten basic S1 patterns, there were also a similar number of basic S2 patterns. The only variation in either of them was due to the random placement of the *real* and *pseudo* missing dots. This raised a potential problem because it was possible that subjects would learn to recognise the limited number of S2 patterns and associate them with their complementary S1 patterns (they had opportunities to accomplish this learning process during practice trials). This eventuality could lead to spurious conclusions. Subjects applying this strategy might find that S2 became more discernable as

Sd2 increased because the proportion of time that S1 persistence overlapped with visual activity generated by S2 would decline. The control condition was therefore included in order to check on this possibility.

Aims

To replicate the finding that temporal integration performance is inversely related to Sd2 whilst demonstrating that letter identification performance is positively related to mask duration.

To confirm that any positive Sd2 effects in the letter identification task were not the result of the paired associate learning of complementary stimulus relationships.

Method

The main experiment provided 3 levels of Sd2; these were 1, 50 and 100 ms. These temporal conditions were applied in both the missing dot and letter identification report modes. In addition, and after the above conditions had been run, three (out of six) subjects undertook two further levels of Sd2; these were 10 and 30 ms. The purpose of this was to fill out the performance curves and help to consolidate the results of the experiment. Sd1 and ISI always remained constant.

All stimuli in the missing dot and letter identification tasks were designed to a similar format. The S1 dot designs could represent any of the following 10 letters: *A, C, E, H, M, P, S, U, W, Z.*

In the control sessions, the S1 dots were never actually presented. In two thirds of all trials, the back-

grounds (i.e. the S2 dot patterns) were the complement of the usual S1 letter designs. A subject's task was to guess the identity of the complementary letter. It was reasoned that if performance in this exercise reached a high standard then subjects could well have used knowledge of S2 patterns to perform the experimental letter identification task. Clearly, such a result would challenge the basic premise of this experiment.

A further danger was that S's could have become particularly sensitized to S2 designs by the control procedures. This might have encouraged subjects to utilize the very strategy that the experimenter wished them to avoid, namely that they would associate the S2 designs with the relevant S1 letters. Therefore, in order to counter this possibility, five novel S2 designs were included in one third of all control trials. These designs were based on the complements of five extra S1 characters which subjects never saw: *B*, *D*, *G*, *O* and *3*. It was thought that the inclusion of these extra shapes would dilute any associative learning that might occur during these sessions.

In order to obtain the best chance of letter masking by S2, it was important that there was as little apparent contrast as possible between S1 and S2. All stimuli were therefore equated for brightness on an individual subject basis (as with Expt. 3).

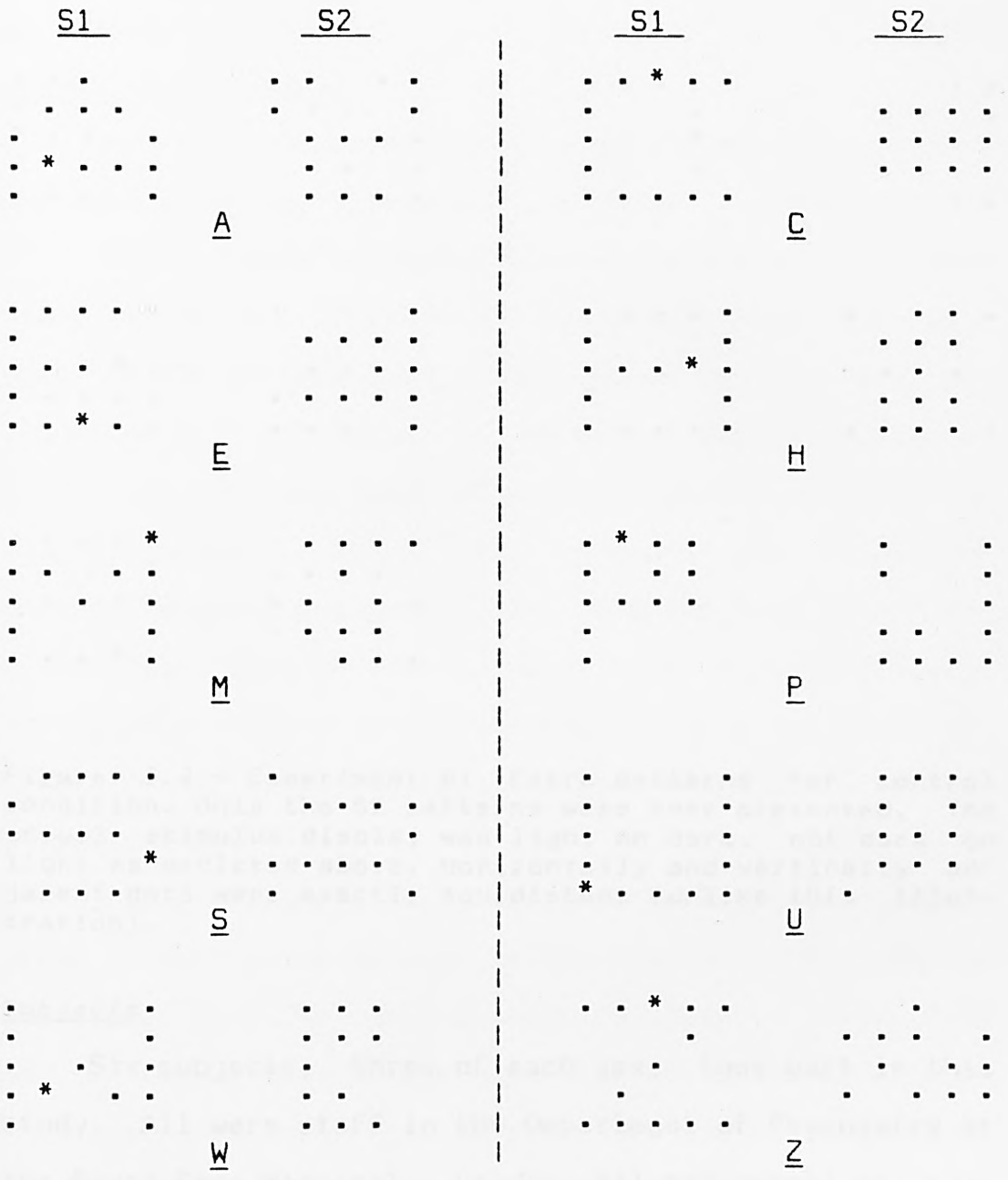


Figure 3.1 - Experiment 6: Leading (S1) and following (S2) stimulus patterns. The asterisk fills the position of the pseudo missing dot. The actual stimulus display was light on dark, not dark on light as depicted above. Horizontally and vertically adjacent dots were exactly equidistant (unlike this illustration).

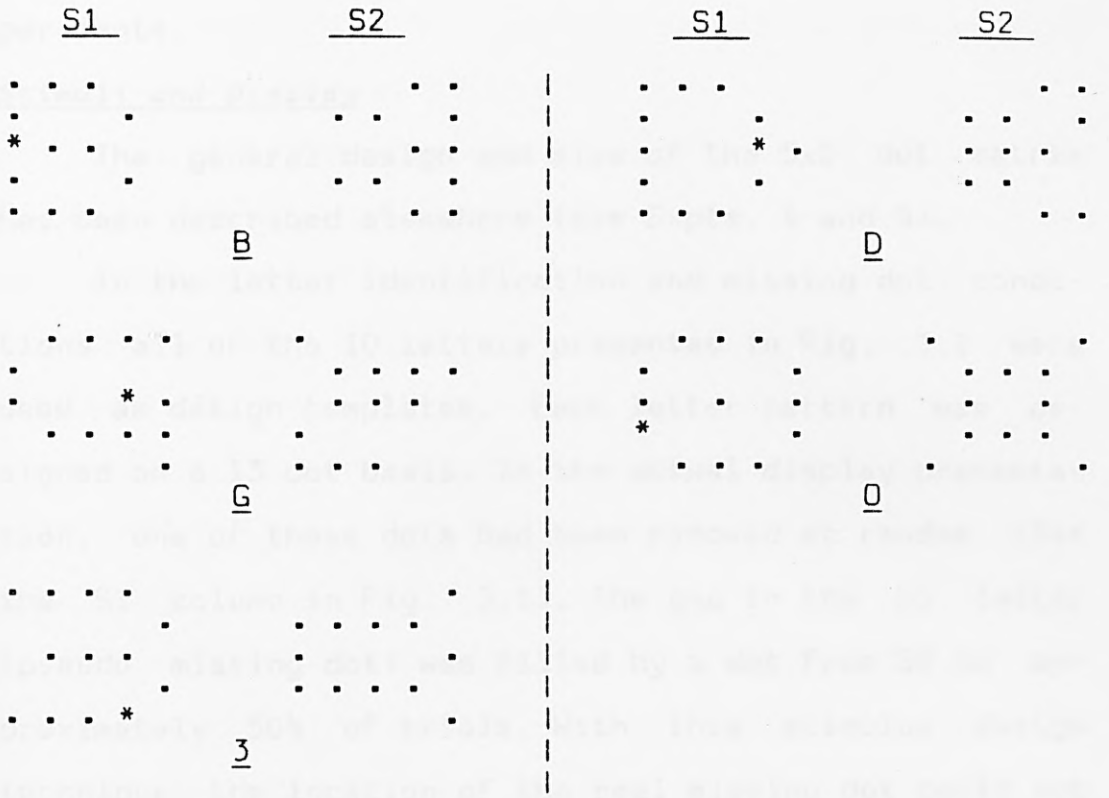


Figure 3.2 - Experiment 6: Extra patterns for control condition. Only the S2 patterns were ever presented. The actual stimulus display was light on dark, not dark on light as depicted above. Horizontally and vertically adjacent dots were exactly equidistant (unlike this illustration).

Subjects

Six subjects, three of each sex, took part in this study. All were staff in the Department of Psychiatry at the Royal Free Hospital, London. All had normal or corrected to normal vision and English was their first reading language. Their ages ranged from 19 to 33 years old with a mean of 26 years.

Two of the males and one female were locum staff and had left the hospital before the extra conditions, described above, could be run.

Apparatus and software

All the apparatus was identical to that used in the empirical work reported in previous missing dot ex-

periments.

Stimuli and Display

The general design and size of the 5x5 dot matrix has been described elsewhere (see Expts. 4 and 5).

In the letter identification and missing dot conditions all of the 10 letters presented in Fig. 3.1 were used as design templates. Each letter pattern was designed on a 13 dot basis. In the actual display presentation, one of these dots had been removed at random (See the S1 column in Fig. 3.1). The gap in the S1 letter (pseudo missing dot) was filled by a dot from S2 in approximately 50% of trials. With this stimulus design technique, the location of the real missing dot could not be determined simply by recognising the shapes in either stimulus field.

Stimuli were similarly designed for the control sessions, with two exceptions as follows: (1) The design templates included the 5 characters shown in Fig. 3.2; and (2) the S1 dots in the actual presentation were presented at zero intensity. Thus, in effect, only the 12 S2 dots were displayed in these trials.

Letters and missing dot locations for the 100 trials in each session (except control) were randomized, with the following constraints: (1) Each of the ten possible letters was presented ten times and five of these occurred over the final 50 trials; and (2) every matrix location was a missing dot target four times, twice in the last 50 trials.

Presentations of the S2 designs in each control session (which each consisted of 30 trials) were random.

This was constrained so that each of the fifteen possible designs was presented twice.

The data for brightness matching were obtained from a previous study (see Appendix 1: Pilot 4). S1 was always presented at a dot luminance of 5.39 cd/m^2. The dot luminances that were used in this experiment are displayed in Table A1.5.

The usual eye fixation stimulus was presented on each trial.

Procedure

The laboratory arrangement and subject viewing distance remained the same as in the previously described missing dot experiments. The rest of the experiment was also run on similar lines with a few exceptions.

Missing dot and letter identification report sessions were kept separate so that half the subjects undertook all the main missing dot conditions first and half of them undertook letter identification first (main temporal conditions refer to where Sd2 was 1, 50 or 100 ms). The secondary temporal conditions (i.e. where Sd2 was 10 or 30 ms) were run afterwards, commencing with the report condition in which the subject had begun the experiment. All temporal conditions were randomized for each subject and blocked between sessions. Sd1 and ISI were 1 ms and 40 ms respectively.

Missing dot sessions:

Missing dot sessions (containing 10 practice and 100 experimental trials) have been described previously (see Expts. 3, 4 and 5). The usual full practice session was also provided prior to commencement of experimental ses-

sions.

Letter identification sessions:

In these sessions, the 100 experimental trials were always preceded by 20 practice trials. In the first ten of these, the S1 display was presented for 1 ms without S2. Each of the ten letters (minus one element) was shown and the subject's task was to identify it. Feedback was given and the point of this practice was to remind S's about letter designs. In the following ten trials, the successive fields were presented under the prevailing temporal conditions of the session. Each of the ten letters was again presented and feedback was again provided after every trial. In the following experimental trials, feedback was withdrawn.

Subjects also undertook one session, consisting of 120 trials, that was devoted entirely to practice. This was given prior to experimental letter identification sessions. In the first twenty of these, each of the 10 stimulus letters was presented twice (in random order), without the following S2 field. The purpose of these trials was to familiarise S's with the letter shapes.

In the final 100 trials of the practise session, both fields were presented successively at 1, 2 and 1 ms for Sd1, ISI and Sd2 respectively. At these short durations temporal integration was expected to be extremely good and so letter masking should have been strong. Therefore, in order to reduce this masking effect, the dots in the S2 field were presented so that they appeared to be much dimmer than S1 dots (S1 dot luminance was 5.39 cd/m^2 and S2 dot luminance was 1.573 cd/m^2). In this way,

the letter appeared to stand out more brightly in contrast to the S2 dots (in fact this was the smallest contrast for which an identification performance of greater than 50% could be obtained). The purpose of these trials was to give subjects some practice at distinguishing the S1 shapes from the visual noise generated by S2. Feedback was given after every trial.

Control sessions:

A control session always commenced immediately after completion of an experimental letter identification session. Subjects were instructed to respond with the letter that they thought was associated with the background dot pattern. They were aware of the 5 extra S2 patterns but not of their S1 identities. Subjects were told to respond with "other" if they thought that the pattern was not part of the original set.

It was further impressed upon them that they should answer as quickly as possible on a recognition basis rather than by attempting to infer the complementary shape by logical analysis of the empty dot locations (no subject, including the experimenter, found logical analysis to be easy; this was confirmed in a post-experiment debriefing).

The S2 (background) stimulus in this condition was always presented for a duration of 100 ms, at the subject's tailored luminance.

General:

Each experimental trial sequence was similar to that described in previous missing dot reports. The other report conditions differed only in respect of the type of

response provided by S (as well as the omission of the S1 field in the control sessions).

By the end of the experiment, half the subjects had completed 6 experimental sessions plus 3 control sessions, while the other half had completed 10 experimental sessions and 5 control sessions. Missing dot and letter identification sessions lasted for between 10 and 15 minutes.

Results and Discussion

All scores were converted into percentages, the mean results being shown in Tables 3.1 and 3.2. They are also shown in graphical form in Figure 3.3. Individual results are depicted in Figures 3.6 to 3.11. The data for the control condition were taken only from trials where the S1 symbol had been one of the ten original letters. Thus ten trials per control session were excluded from analysis.

Since extra Sd2 conditions (i.e. where Sd2 was 10 ms and 30 ms) were run after the main conditions, and hence were probably confounded with practice effects, they were not included in any of the statistical analyses that are reported below.

The percentage of total errors, where the missing dot was incorrectly located at S1 dot coordinates (% 1st Error), was calculated and the mean results are shown in Table 3.1 and Figure 3.4.

Missing Dot Task

% Correct	Std.Dev.	% 1st Err.	Std.Dev.	Sd2(ms)	N
91.1667	10.9072	50.0933	34.9612	1 "	6
88.3333	8.0208	41.2133	20.0553	10 "	3
77.6667	14.7422	61.3333	2.4166	30 "	3
72.5000	13.9104	81.0967	11.5546	50 "	6
40.0000	13.3566	81.6917	15.3447	100 "	6

Table 3.1 - Experiment 6: Mean % Correct and % 1st Error scores in the missing dot task. The N column refers to the number of subjects.

Letter Identity and Control Tasks

Letter identity		Control			
% Correct	Std.Dev.	% Correct	Std.Dev.	Sd2(ms)	N
53.3333	15.0422	27.5000	9.3541	1 "	6
79.6667	10.4083	31.6667	7.6376	10 "	3
89.0000	6.0828	38.3333	10.4083	30 "	3
84.3333	7.4476	35.8333	15.3025	50 "	6
89.8333	6.1128	32.5000	12.9422	100 "	6

Table 3.2 - Experiment 6: Mean % Correct scores in the letter identification and control tasks. The N column refers to the number of subjects.

The mean results (% Correct data) showed a monotonic decline in missing dot performance as Sd2 increased. Letter identification performance, on the other hand, showed a positive relationship with Sd2. The improvement with increasing Sd2, in the latter report condition, was not entirely monotonic but this seems likely to have been due to practice effects in the 10 and 30 ms Sd2 conditions. The Task x Sd2 interaction was shown to be highly significant in a 2 way ANOVA (see Table 3.3). The significance of the main effects was compromised by this interaction but they were shown to be highly significant when two 1 way ANOVA's were computed (see Table 3.4).

All individual performances showed similar results to those depicted by the means (Figs. 3.6 - 3.11).

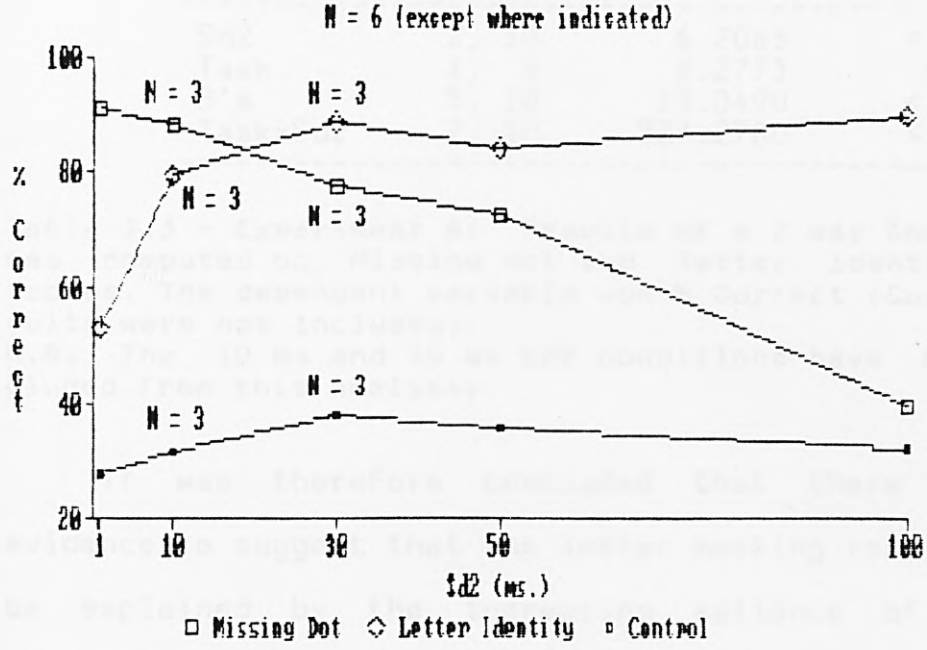


Figure 3.3 - Experiment 6: Mean % Correct scores in the missing dot, letter identification and control sessions, as a function of Sd2. Note that for the control sessions all stimuli were presented for 100 ms and that the Sd2 function there relates to the complementary Sd2 condition of the preceding letter identification session.

Performance in the control condition was much poorer than for experimental letter identification at all levels of Sd2. It was thought that if S was taking any cognisance of the S2 pattern in the latter conditions then performance in the control might be facilitated when the associated Sd2 condition was long. The mean results show that there is little support for this argument. Performance (in the controls) did increase slightly where the Sd2 in the concomitant letter report condition lengthened from 1 to 30 ms. There was no change when Sd2 was greater than 30 ms. When control data were analysed in a one way ANOVA (the factor levels were the Sd2 values in the corresponding letter identification condition) no significant effects were found (see Table 3.4).

SOURCE	df	F	p
Sd2	2, 10	6.2065	<.025
Task	1, 5	2.2773	n.s.[1]
S's	5, 10	13.0490	<.001
TaskxSd2	2, 10	227.2780	<.001

Table 3.3 - Experiment 6: Results of a 2 way ANOVA that was computed on Missing dot and letter identification scores. The dependent variable was % Correct (Control results were not included).
N.B. The 10 ms and 30 ms Sd2 conditions have been excluded from this analysis.

It was therefore concluded that there was no evidence to suggest that the letter masking results could be explained by the increasing salience of the S2 stimulus pattern caused by an increasing Sd2. Subjects did not learn to associate the complementary S1 and S2 stimulus patterns to a great enough degree to recognise S2 patterns and to use this information to identify S1 in the letter identification task.

There was a tendency for the % 1st Error (missing dot) to increase with Sd2 and this was shown to be marginally significant in a 1 way ANOVA (see Table 3.4 and Figure 3.4). These errors increased to over 60% when Sd2 was 30 ms and reached an asymptote at over 80% when Sd2 was 50 ms. These findings are similar to the non-significant results reported in Expt. 3. They support the notion that persistence from S1 decays over the whole period of S2 presentation before it can be utilized for perceptual integration.

[1]not significant

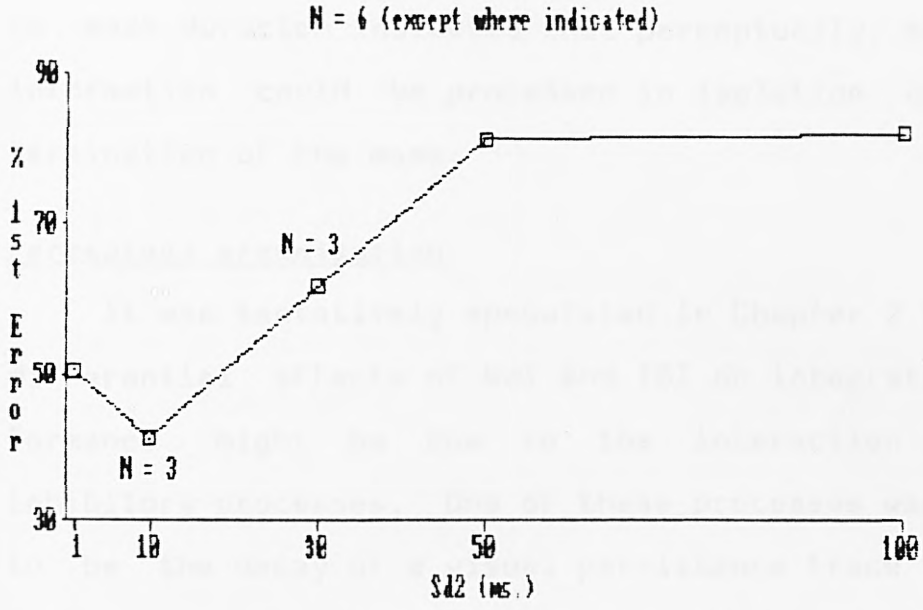


Figure 3.4 - Experiment 6: Mean % 1st Error scores as a function of Sd2. These data were obtained from missing dot sessions.

Dep.Vble.	Task	df	F	p
% Correct	Letter ID.	2, 10	35.0453	<.001
"	Miss. Dot	2, 10	84.6493	<.001
"	Control	2, 10	0.5901	n.s.
% 1st Error	Miss. Dot	2, 10	4.4671	<.05

Table 3.4 - Experiment 6: Results of various 1 way ANOVA's computed for Sd2 (the source in the control condition was the Sd2 in the concomitant letter ID condition).
N.B. The 10 ms and 30 ms Sd2 conditions have been excluded from this analysis.

It seems reasonable to conclude from these results that target and mask remained perceptually segregated until the offset of the mask (S2). Persisting visual information about S1 could apparently be utilized in a segregation task (letter identification) even when the same information could not be integrated with visual data generated by a second stimulus field. The fact that

letter identification performance was positively related to mask duration indicated that perceptually segregated information could be processed in isolation until the termination of the mask.

Perceptual organization

It was tentatively speculated in Chapter 2 that the differential effects of Sd1 and ISI on integration performance might be due to the interaction of two inhibitory processes. One of these processes was thought to be the decay of a visual persistence trace but the other has, so far, not been identified. However, it seemed possible that it might have something to do with the idea of perceptual segregation. As will be seen below, there is some evidence, from the present experiment, to support of this. However, in order for the following argument to be fully comprehensible, a short digression becomes necessary.

It has been speculated that at the early stages of visual processing the stimulus features represented in a visual store may be little more than a chaotic jumble of dots and bars and other unconnected visual features (Di Lollo, 1980). Even though these features may be organised on a retinotopic basis, order might still need to be imposed by feature analysers and perhaps other visual information processes, so that meaningful perceptions can be extracted. Evidence in support of this can be found in clinical case histories where visual deficits have been caused by various neurological traumas. For example, Efron (1968) describes a patient who was suffering from a

certain form of brain damage incurred by carbon monoxide poisoning. He was unable to interpret even the simplest picture or scene even though his intellectual faculties were intact and he was able to see contours and individual features quite clearly. The problem, in his case, seemed to be that he was unable to perceive individual contours in relation to each other and thus was unable to project a sense of meaning into his visual environment. A number of similar cases are described by Sacks (1985), although in a less scientifically rigorous manner.

It became apparent, in the present experiment, that the observers did project visual constructs onto the stimulus displays. The combined missing dot stimulus was merely a collection of 24 dots arranged symmetrically, and yet the perception that was generated by this collage (when the probability of integration was good) was that of a square made up of rows and columns of dots (this seemed a reasonable description in the writer's opinion and was supported in informal interviews with subjects). There were no explicit lines linking dots in the display so, in a sense, the perceived arrangement was imposed by the observers themselves. It so happened that this perceptual construct would have been compatible with the co-ordinate report system that was used to identify the location of missing dots (see Expt 3). Seeing the dots arranged into a series of diagonal lines would have been just as valid a perception but it would not have been particularly useful for indicating dot locations when using the report method that was employed in these experiments.

It is conceivable that each stimulus field, if viewed in isolation, might have encouraged observers to generate a perceptual construct other than rows and columns. For example, the row and column type of imposed visual construct would not have aided in the identification of the letter *S* as described by some S1 stimuli. Each different shaped stimulus field might well encourage a different perceptual construct. Thus, in the successive field presentation it is possible that the longer that the visual information about each stimulus field remained perceptually segregated, then the more time there was available to impose perceptual constructs which may have been incompatible with the perception of a fully integrated matrix. If, by the time integration was triggered, the elements within just one stimulus field had become perceptually arranged into a format that was incompatible with the full square matrix then perceptual integration may have become inhibited. The putative second inhibitory influence on integration (i.e. the alternative process to persistence decay) might therefore reflect the degree to which each stimulus field had been individually processed. Insofar as this process would be expected to take some time, its power to inhibit integration may have increased as the total display duration increased.

In the present experiment, some of the S1 shapes were probably more compatible with the row and column format than others (see Fig. 3.1). For example, the *C* was described by filling 3 sides of the matrix and therefore somewhat anticipates the shape of the integrated display form. On the other hand, the *S* bore little resemblance to

the square shape of the matrix. This range of shapes means that letters may have produced differential effects on missing dot performance.

Because the S1 field had more time than the S2 field to be processed it seems reasonable to suppose that the shape of the former field would have had the greatest influence. According to the hypothesis under discussion the less compatible the S1 shape with the full matrix then the less likely that temporal integration would be successful.

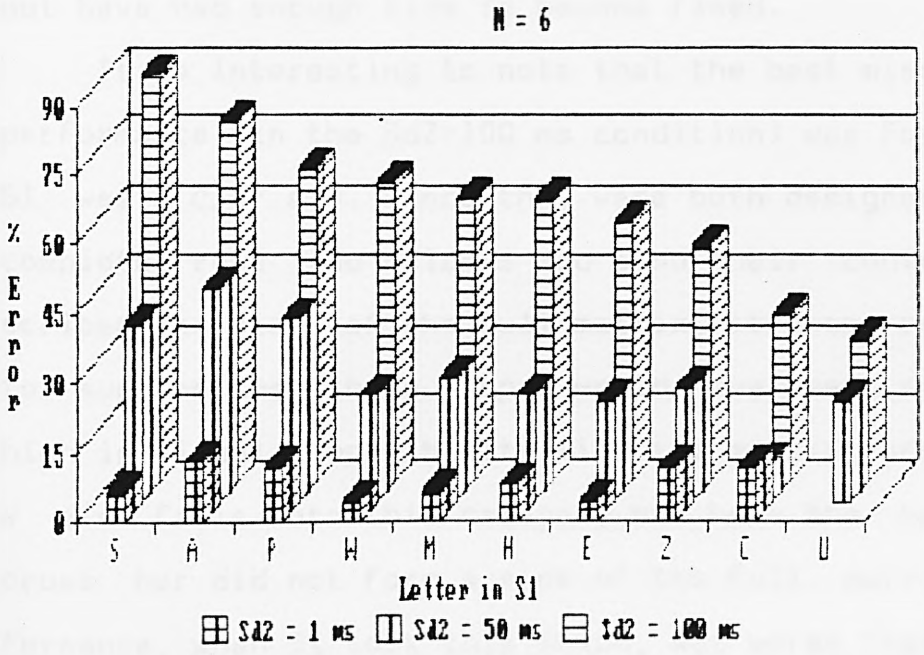


Figure 3.5 - Experiment 6: 3D bar graph of missing dot scores according to the letter symbol presented in the 1st stimulus field. The dependent variable is % Error.

Figure 3.5 shows a 3D bar graph of the percentage error rate in the missing dot task, related to the letter in S1. Each of the three Sd2 conditions that were undertaken by all subjects (i.e. where Sd2 was 1, 50 and 100 ms) is represented. It can be seen that missing dot

performance did vary between S1 letters. In a two way ANOVA, the main effect of letter was computed to be highly significant ($F_{letter}=6.284$; df=9, 45; $p<.001$). There was also a highly significant letter x Sd2 interaction ($F_{letter \times Sd2}=3.466$; df=18, 90; $p<.001$). This seems to have come about because the relationship between S1 letter identity and performance broke down at the short Sd2. In fact, this result would have been expected since a 1 ms Sd2 would have caused integration to be triggered at an early point in stimulus processing. Thus, perceptual constructs for the individual stimulus fields may not have had enough time to become fixed.

It is interesting to note that the best missing dot performance (in the Sd2=100 ms condition) was found when S1 was a *C* or a *U*. Since they were both designed out of complete rows and columns and also their contours described the sides of the full matrix, it seems reasonable to suppose that these shapes would have been relatively high in visual compatibility with the matrix format. The *H* also falls into this category but here the horizontal cross bar did not form a side of the full matrix. Performance, when S1 took this shape, was worse than C and U in the longest Sd2 condition. The *S* was not designed from a complete row or column and this character is associated with the poorest missing dot performance (when Sd2 was 100 ms). Furthermore, if this letter was identified at some processing level prior to integration, then a highly incompatible construct might have been imposed because the letter *S* is more familiarly seen to be drawn with curved lines.

Other letter shapes may have been more or less perceptually compatible with a square dot matrix form. However, apart from the letters discussed above, the question of their visual compatibilities with the square dot matrix may be largely a matter of differing personal opinion. In general these results support the hypothesis that the shape of the stimuli within each successive field did influence integration. Furthermore, as the symbol shape in S1 became less compatible with that of the full matrix, integration performance was less likely to be successful. One other problem here is that the shape of the following stimulus may also be important as this could also be expected to influence integration. There is no *a priori* reason to suppose that S2 would not also undergo some feature analysis prior to its physical termination. It is therefore possible that the shape of one successive field may be compatible whilst the other may not be. This possibility might need to be considered in any future investigations.

Of course the above discussed hypothesis can only be tentative. There may be alternative explanations that do not rely entirely on the shape of the stimulus fields. For instance dot density, rather than stimulus pattern, might have been the relevant variable (the dots in some letters and their complementary backgrounds were more spread out than others). This, in turn, might implicate the role of spatial frequency in persistence duration. Nevertheless, the present writer favours the original hypothesis since it manages to explain the inverse Sd1 effect without recourse to persistence.

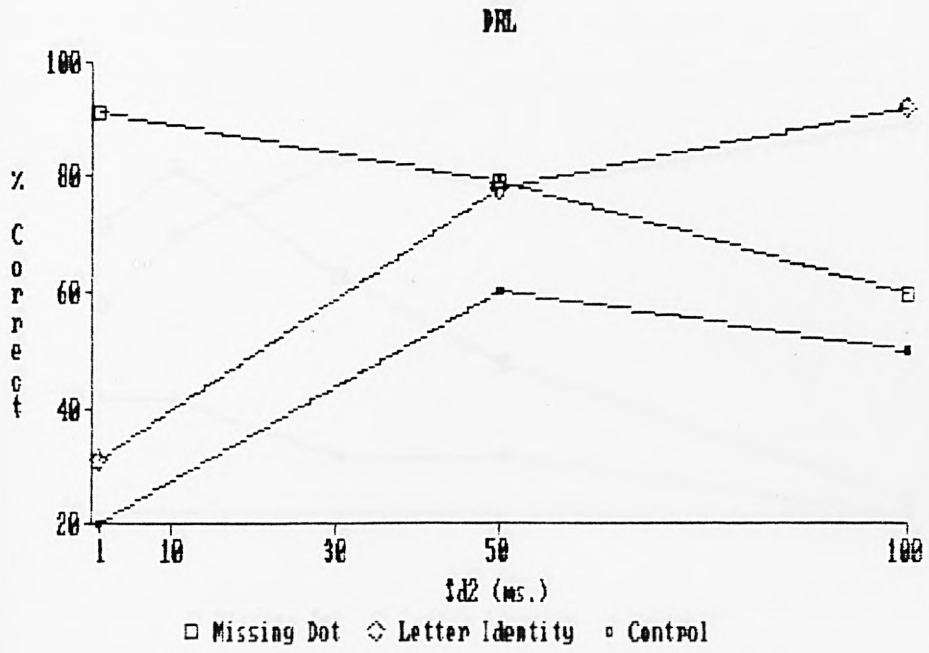


Figure 3.6 - Experiment 6: % Correct scores for subject DRL in the missing dot, letter identification and control sessions.

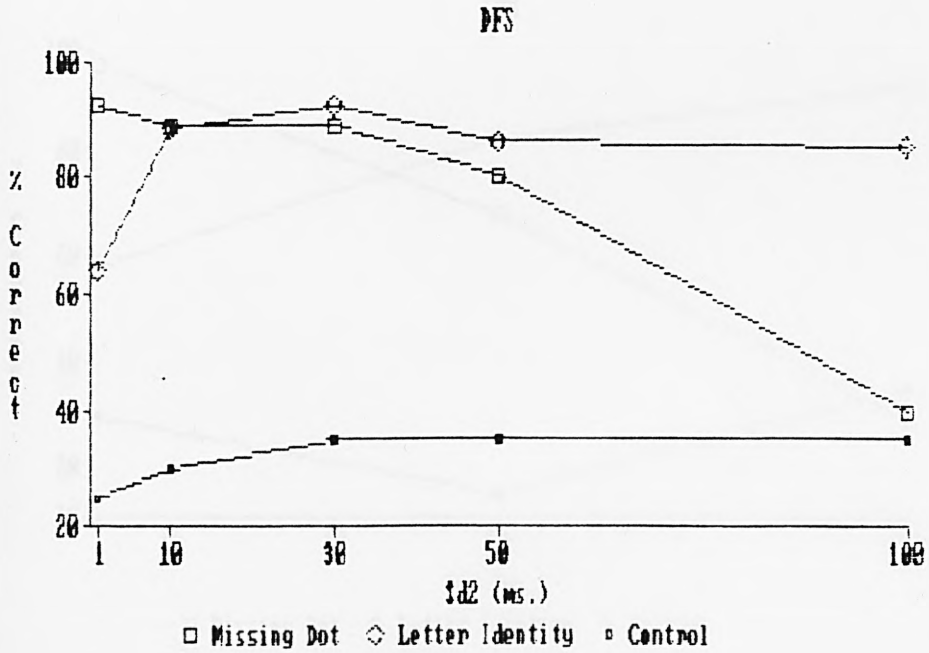


Figure 3.7 - Experiment 6: % Correct scores for subject DFS in the missing dot, letter identification and control sessions.

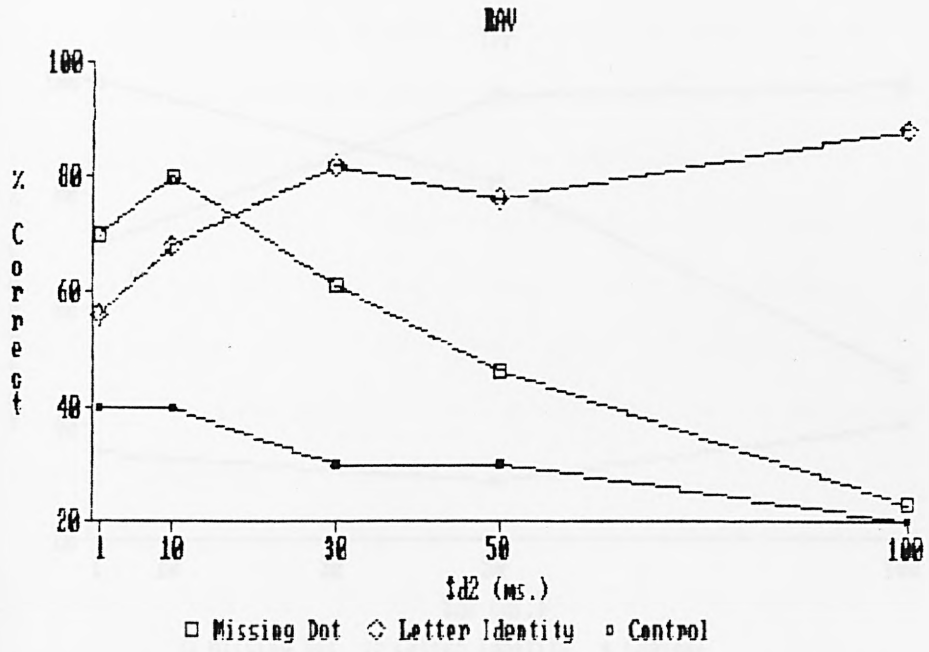


Figure 3.8 - Experiment 6: % Correct scores for subject RAV in the missing dot, letter identification and control sessions.

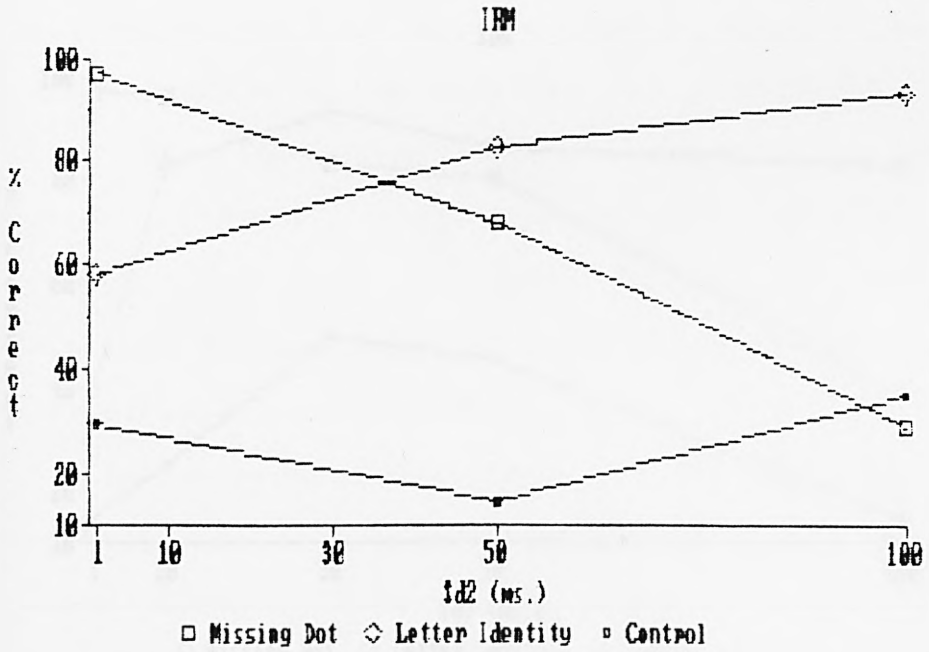


Figure 3.9 - Experiment 6: % Correct scores for subject IRM in the missing dot, letter identification and control sessions.

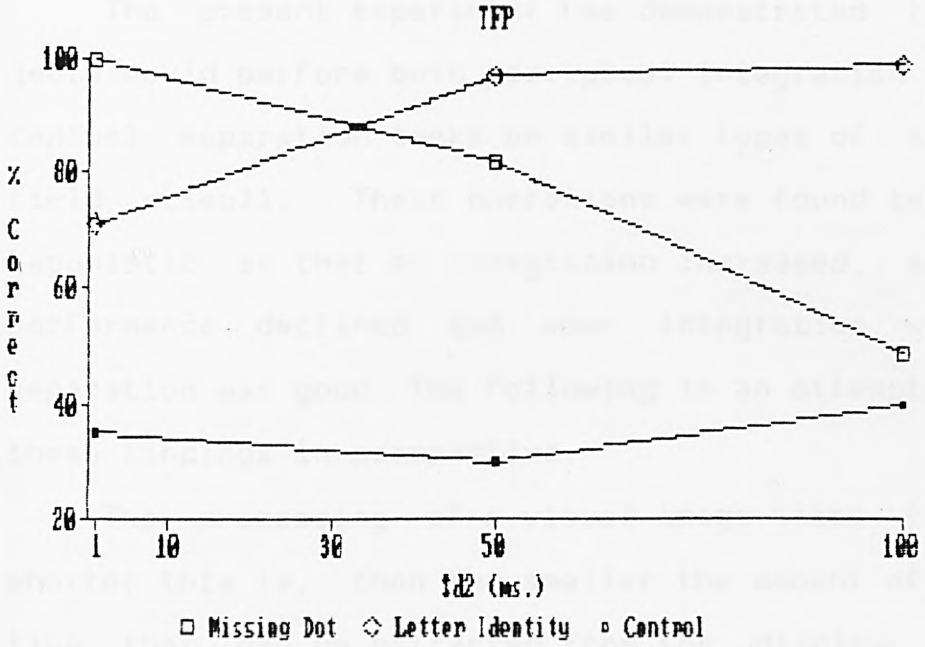


Figure 3.10 - Experiment 6: % Correct scores for subject TFP in the missing dot, letter identification and control sessions.

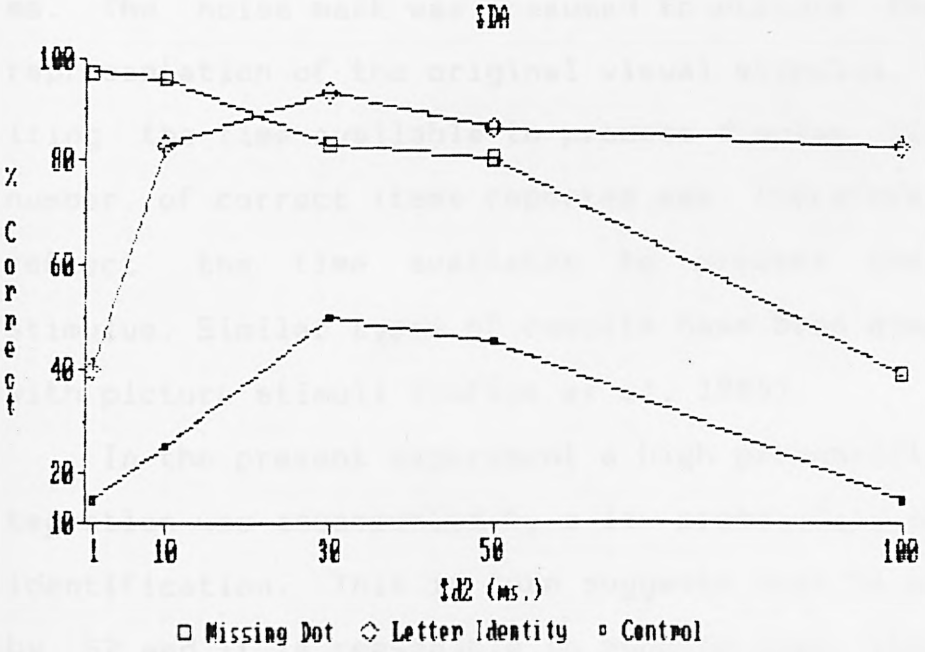


Figure 3.11 - Experiment 6: % Correct scores for subject SDA in the missing dot, letter identification and control sessions.

Perceptual integration and perceptual segregation

The present experiment has demonstrated that subjects could perform both perceptual integration and perceptual separation tasks on similar types of successive field stimuli. These operations were found to be antagonistic so that as integration increased, separation performance declined and when integration was poor, separation was good. The following is an attempt to place these findings in perspective.

The processing of a visual image takes time. The shorter this is, then the smaller the amount of information that can be extracted from the display. Sperling (1963) showed that if a letter display was followed by a visual noise mask then the number of items that could be reported increased rapidly as SOA was increased to 100 ms. The noise mask was presumed to obscure the iconic representation of the original visual stimulus, thus limiting the time available to process display items. The number of correct items reported was therefore held to reflect the time available to process the visual stimulus. Similar types of results have been demonstrated with picture stimuli (Loftus *et al*, 1985).

In the present experiment a high probability of integration was accompanied by a low probability of letter identification. This in turn suggests that S1 was masked by S2 and it is reasonable to suppose that this effect was caused by camouflage. In other words, when integration was good, S1 and S2 could not be easily distinguished. In that case, the time available to process S1 prior to integration was insufficient for identification

purposes. Nevertheless, as Sd2 increased letter identification *did* improve. This suggests that the amount of time available to process S1 increased. However, since SOA did not vary, extra processing time would not have been available if integration occurred at the onset of S2 (or at some other constant latency). The answer may be that the latency of integration was variable because the successively presented stimuli remained perceptually segregated until the offset of S2. Thus, as the total combined display duration increased, then more time would be available to process each stimulus field individually (in the present situation total display duration was increased by increasing Sd2).

The above explanation accords well with the temporal segregation hypothesis that was developed in Chapter 2. There it was demonstrated that integration was not triggered until an offset signal was detected within, or at the termination of, S2. However, in order for this to be possible, visual information about each successive field would need to remain in perceptual isolation, within the nervous system, until the moment of integration. This idea was tested in Expt. 6 which was apparently able to demonstrate that segregation (i.e. isolation) can occur.

This does not resolve the question about whether visual information begins to be lost soon after stimulus onset or offset. The proposal that integration is triggered at stimulus offset can explain the inverse Sd2 effect but it is also quite compatible with the notion that persistence begins at onset. However, there are two reasons why it might be more helpful to conceive of an

offset decay:

(1) If persistence was generated at stimulus onset then the effects of the mix of Sd1 and ISI within a constant SOA should be irrelevant but it was shown in Expt. 5 (and tentatively in Expt. 1) that the Sd1 function was different to the ISI function (see also Di Lollo, 1980; Hogben and Di Lollo, 1974). It was argued in Chapter 2 that this problem could be resolved if persistence was generated at offset but that a second process was also responsible for inhibiting integration; and (2) divergent findings about the relationship between Sd1 and persistence duration have been reported. This is particularly true as far as direct methods versus indirect methods are concerned (an inverse relationship for array duration in partial report has *never* been demonstrated).

It would be more parsimonious to have a single persistence hypothesis, rather than the multiple persistence type theories that currently abound. Since there have been no controversial findings about the effect of array duration on partial report, the offset hypothesis might be considered to be more appealing.

One other contribution of Expt. 6 was the tentative offer of a mechanism that just might explain the inverse Sd1 effect without recourse to persistence. It was demonstrated that the visual form of the first stimulus was influential in determining the probability of temporal integration. When this form was incompatible with the organised visual structure of the (would be) montage then integration was progressively inhibited as Sd2 increased. The more compatible shapes seemed to cause less inhibi-

tion. This suggested that there was an inverse relationship between the degree of perceptual organization of, at least, the first field and the probability of integration at the offset of S2. The mooted "other" process might therefore reflect the degree of visual processing of perceptually isolated stimuli. Its power to inhibit integration would be an increasing function of Sd1 (and perhaps total display duration) even if persistence only begins to decay after stimulus offset.

It seems that the greater the degree to which a field has become feature analysed, at the termination of the full display, then the less the propensity for perceptual integration. Or, in other words, the greater the perceptual organization of the first (and perhaps the following) stimulus, the greater the probability that successive fields will remain perceptually dissociated.

In summary, the model developed so far (hereafter called the *dissociation* hypothesis) incorporates three ideas about temporal integration:

(1) There is a global loss of visual information. This loss probably begins after stimulus offset although this was not entirely certain.

(2) Successive fields remain perceptually segregated until following field offset. Thus, the strength of persistence is important to perceptual integration only after the whole display has terminated.

(3) The degree of perceptual integration is inversely related to the degree of perceptual organization that has been achieved by the time the whole display has terminated. The degree of perceptual organisation in-

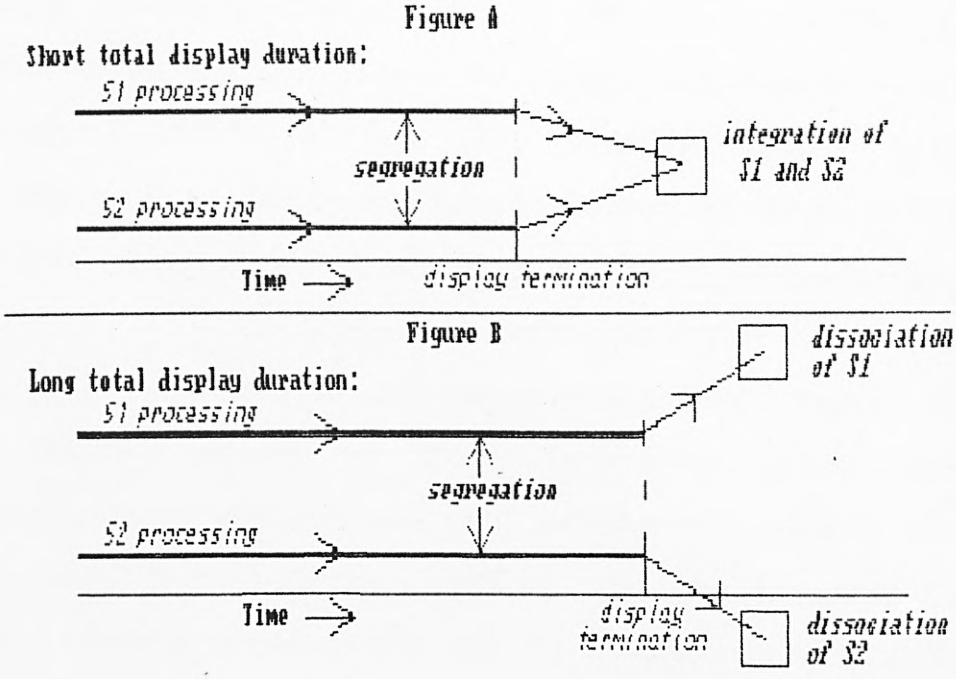


Illustration of hypothetical distinction between perceptual segregation, perceptual integration and perceptual dissociation.

Figure A: This figure depicts the situation where total display duration is short. S1 and S2 are processed in perceptual segregation until the second of two successive fields has terminated. Because of the short display duration, perceptual organization of S1 and S2 has not proceeded very far by S2 offset. The two stimuli can therefore be processed further but this time there are interactions between them. It was thought that this condition would allow successful perceptual integration.

Figure B: This figure depicts the situation where total display duration is long (relative to A). Again, S1 and S2 are processed in perceptual segregation until the final termination of the display. At S2 offset an attempt may be made to process S1 and S2 together but, since at least one field has had enough time to attain a high degree of perceptual organization, the two stimuli cannot become amalgamated. In this case perceptual dissociation ensues.

creases from stimulus onset. Thus, the longer the total display duration, the greater the degree to which successive fields will remain perceptually dissociated after the full display has terminated.

Thus, the two processes which were held to limit integration performance have been tentatively identified. The first of these is global persistence decay and the second is the tendency towards perceptual dissociation[1]. *page opposite*

Relative stimulus field contrast

The concept of perceptual segregation is perhaps something of a radical departure from current ideas about temporal integration (although Intraub 1984, 1985 has suggested something similar in respect of short term visual memory for pictures). Under the banner of caution, therefore, an alternative explanation for the inverse effect of Sd2 on masking was sought.

There is one possible way that the masking results might have occurred without the stimulus fields remaining perceptually isolated during successive field display presentations. If the persistence from S1 had followed a Type II decay curve then it is possible that the S1 stimulus sometimes appeared to be dimmer than the S2 stimulus when a response was being selected. Furthermore, it might be expected that this negative contrast would have increased as Sd2 increased: A long S2 would give more time for S1 persistence to fade than a short S2. If

[1]Dissociation is what happens after integration has been triggered. Segregation, in contrast, is the process that occurs before display termination.

subjects could make use of this inverse contrast to differentiate the S1 and S2 dot elements, then performance in the letter report condition would have been positively related to Sd2.

This possibility was explored in Experiment 7. Also, since brightness was going to be an independent variable anyway, the opportunity was taken to make a limited investigation of the more general effects of energy on both letter masking and temporal integration.

Two temporal conditions were repeated from Expt. 6. This time, however, the brightness of S2 was also manipulated so that it could be much dimmer or much brighter than S1. The bright S2 condition would create an inverse contrast situation and thus enable the above discussed hypothesis to be investigated.

It was also of interest to investigate the effects of stimulus contrast on missing dot performance. Experiment 4 had left an open question as to whether a simple brightness imbalance between successive fields might adversely affect missing dot performance. It had been shown that this did not happen when Sd2 was long, but then integration would have been poor anyway. The interest here was to see what would happen when Sd2 was shorter so that integration was relatively good.

Experiment 7: Inter-field contrast in temporal integration and backward masking

Introduction

The present experiment was a partial repeat of Expt. 6, but the relative contrast between S1 and S2 was also manipulated. This was achieved by altering S2 intensity while S1 intensity remained constant throughout the experiment. The advantage of this method was that any attributes of persistence that were generated by S1 should have remained unchanged. It was noted in Chapter 1 that direct methods of measuring persistence (e.g. the judgement of synchrony technique) have indicated that persistence duration varies inversely with stimulus energy.

One major interest of this experiment was to determine whether letter identification would be improved when S2 was brighter than S1 (negative contrast), as compared to when they were of apparently equal contrast. If this did happen then the conclusions about successive field segregation that had been derived from Expt. 6 would be weakened.

Performance was expected to be improved when S2 was dimmer than S1 because the positive contrast would probably result in S1 dots being seen to stand out from the S2 dots. In fact, Expt. 6 made use of this phenomenon in order to provide practice conditions. Nevertheless, it was interesting to include this condition to see whether Sd2 effects would still be obtained when S2 was relatively dim.

Missing dot conditions were also included in order

to investigate the effects of relative brightness on integration. The results from Expt. 4 had tentatively suggested that performance would decline when S2 was brighter than S1, in temporal conditions where integration was expected to be quite probable.

Aims

To determine whether an inverse contrast differential between S1 and S2 would produce an advantage to letter identification.

To further investigate the effects of S2 brightness on integration.

Method

There were two levels of Sd2, these were 10 and 100 ms. Sd1 and ISI remained constant at 1 and 40 ms respectively.

The three levels of S2 brightness resulted in this stimulus being much brighter than (high brightness condition), approximately equal in brightness to (medium brightness), or much dimmer (low brightness) than S1. S2 intensity was adjusted so that brightness sensations were approximately equivalent across temporal conditions.

The two tasks were missing dot location and letter identification. The ten S1 letters were A, C, E, H, M, P, S, U, W and Z (see Fig. 3.1).

Subjects

One male and one female subject took part in this experiment. Both of them had previously undertaken all the conditions in Expt. 6. They were therefore well practised in both report conditions.

Unfortunately, none of the other S's who had taken part in Expt. 6 were available for the present experiment.

Apparatus

The apparatus remained identical to that used in Expts. 3 to 6.

Luminance levels and timings were tested and maintained using the test apparatus that was described in depth in the report on Expt. 3.

Stimuli and Display

The principles of the stimulus designs remained identical to those used in Expt. 6 (see Fig. 3.1). Stimulus spatial dimensions were also identical.

The intensity of S1 was always presented at a dot luminance of 5.39 cd/m^2. The S2 field in the low brightness condition was designed to be approximately equal in brightness to a similar stimulus generated for 10 ms at a dot luminance of 0.162 cd/m^2. The S2 in the high brightness condition was approximately equivalent to a 10 ms stimulus whose intensity was 2.37 cd/m^2. The data for this had been obtained from a previous brightness matching study (see Appendix 2; Pilot 5). For the medium brightness condition, the intensity of S2 was adjusted so that it appeared to be of approximately equal brightness to S1. The data from Appendix 2; Pilot 4 was used for this. All the main stimulus intensities that were employed in this experiment are displayed in Table 3.5.

Brightness Condition	Dot Luminance (cd/m²)	
	Sd2=10 ms	Sd2=100 ms
High	2.370	0.353
Medium	0.661	0.074
Low	0.162	0.019

Table 3.5 - Experiment 7: Three levels of S2 dot intensity used at two levels of Sd2. The high and low levels were based on data obtained from the brightness matching task where the referent was a 10 ms stimulus presented at 2.37 or 0.162 cd/m² respectively (see Appendix 1; Pilot 5). The medium level data was obtained from Pilot 4 (Appendix 1) and represents the means scores obtained between subjects DFS and RAV. S1 was always presented for 1 ms at 5.39 cd/m².

Procedure

All general aspects of the procedure remained similar to those reported previously (see Expt. 6).

All conditions were blocked so that temporal, luminance and task conditions remained constant within a session. Temporal and luminance conditions were randomized for each subject but report conditions followed an *ABBA* order.

Each session consisted of 10 practice trials and 50 experimental trials. Stimulus randomization procedures remained the similar to Expt. 6 after account had been taken of the reduced number of experimental trials.

Sessions lasted less than 10 minutes. Subjects generally undertook two sessions in sequence. However, they were always required to re-adapt to daylight conditions, for about 5 minutes, in between sessions.

Results and Discussion

Graphs of mean individual % Correct scores in the letter identification conditions are shown in Figure 3.12. The missing dot report mode results are shown in

Figure 3.13. The individual data are given in Tables 3.6. and 3.7.

	Sd2=10 ms.			Sd2=100 ms.		
Subject	High	Medium	Low	High	Medium	Low
DFS	92	92	96	100	98	100
RAV	34	62	88	72	86	98

Table 3.6 - Experiment 7: Table of % Correct scores in the letter identification task. The high, medium and low columns refer to S2 brightness conditions (see text).

Letter identification

The positive relationship between letter identification performance and Sd2 was replicated for both subjects. Performance at the long Sd2 condition was always better than in the short Sd2 condition, at each level of S2 brightness.

DFS's performance was over 90% in all letter identification conditions and the benefit of the long Sd2 was therefore only marginal. She was little affected by the S2 brightness condition. When Sd2 was 100 ms, there was a slight improvement of 2% for the low brightness condition when compared with the medium one. However, since this represents a drop from 100% to 98%, it is unlikely that this was a meaningful variation. In contrast, RAV's performance was quite strongly affected by relative luminance. Increasing S2 brightness was clearly detrimental to his performance in both Sd2 conditions. The low S2 luminance level clearly gave advantage to RAV at both Sd2 levels.

It seems clear from these results that there was no performance advantage in having the S1 and S2 stimuli ap-

pear in inverse contrast (i.e. S2 brighter than S1). In fact, this was a disadvantage for RAV. It is interesting to note that even when S1 must have been particularly salient (i.e. in the low S2 brightness condition) performance was better when Sd2 was long rather than short. This seems to confirm the robustness of the positive effect of Sd2 on letter identification.

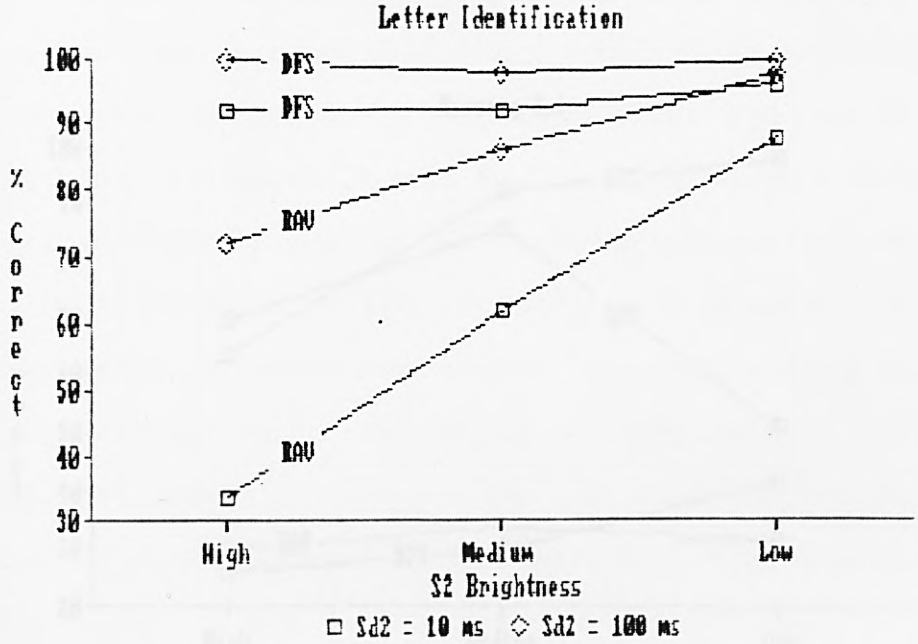


Figure 3.12 - Experiment 7: Graph of % Correct scores for the letter identification task, as a function of S2 brightness.

Missing dot location

The inverse effect of Sd2 on integration was replicated at each brightness level. In the 10 ms Sd2 condition, the effect of the high brightness condition was to depress performance for both subjects. However, the effect of a dim S2 when Sd2 was 10 ms was not so clear. DFS improved slightly in this condition, whereas RAV showed a strong performance deficit. There was little effect of

brightness when Sd2 was 100 ms. Both subjects show uniformly poor performance but this was still above chance probability.

	Sd2=10 ms.			Sd2=100 ms.		
Subject	High	Medium	Low	High	Medium	Low
DFS	64	92	98	26	30	42
RAV	70	86	52	30	34	32

Table 3.7 - Experiment 7: Table of % Correct scores for the missing dot task. The high, medium and low columns refer to S2 brightness conditions (see text).

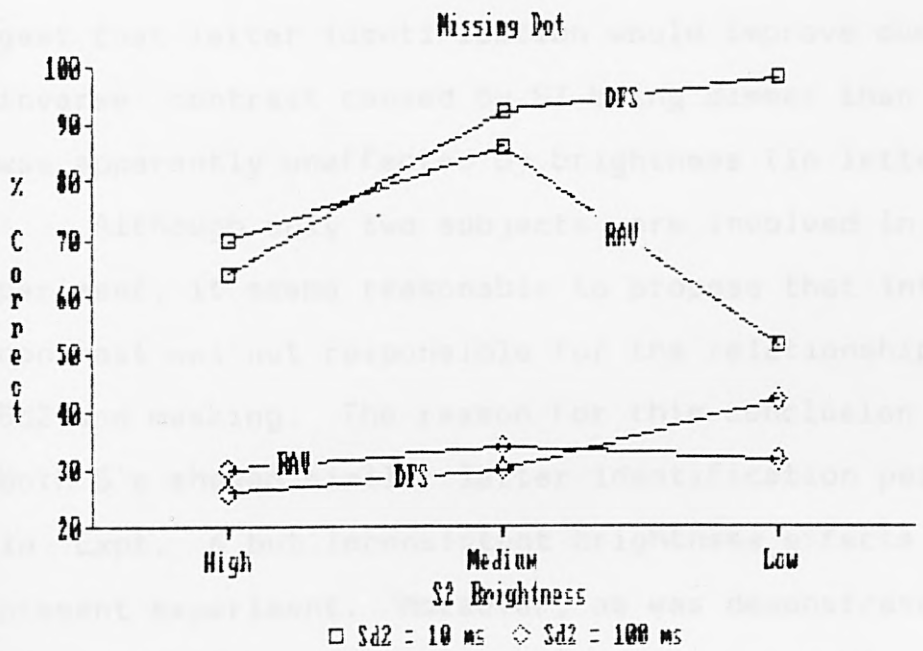


Figure 3.13 - Experiment 7: Graph of % Correct scores in missing dot task as a function of S2 brightness.

The lack of brightness effects when Sd2 was 100 ms could be because integration was already inhibited by the long duration of the following stimulus. Apparent contrast would therefore be expected to play little part in influencing performance. When Sd2 was short and therefore integration processes had a higher probability of success, performance might have had more chance of becoming adversely af-

fected by the relative contrast between fields. Optimum conditions might have occurred when S1 and S2 appeared to be equal in brightness. The inverted *U* in RAV's data supports this hypothesis but DFS's results do so only partially. If, however, DFS's persistence decayed faster than RAV's, then she might have perceived the lowest contrast between stimulus fields when S2 was dim.

Conclusions

The letter task results were not particularly consistent but, even so, there was little evidence to suggest that letter identification would improve due to the inverse contrast caused by S1 being dimmer than S2. DFS was apparently unaffected by brightness (in letter ID).

Although only two subjects were involved in this experiment, it seems reasonable to propose that inter-field contrast was not responsible for the relationship between Sd2 and masking. The reason for this conclusion is that both S's showed similar letter identification performance in Expt. 6 but inconsistent brightness effects in the present experiment. Moreover, as was demonstrated in the present experiment, neither subject apparently benefited from the inverse contrast conditions. In fact, in the case of RAV, this was shown to be highly detrimental to performance. This conclusion is reinforced by the fact that the relationship between masking and Sd2 was replicated at every brightness level even though positive contrast did much to improve performance for one subject (RAV).

Brightness did not affect missing dot performance when Sd2 was long. This result was also noted in Expt. 4.

As suggested previously this finding could be explained because if integration was poor due to the long Sd2 then brightness would not be expected to make a difference.

The results of the missing dot task were not conclusive in the short Sd2 conditions. Both S's showed a performance deficit in the missing dot task when S2 brightness was high. However, when S2 brightness was low one subject improved whereas the other showed impoverished performance.

In conclusion, therefore, it can be stated that although missing dot performance was possibly influenced by S1:S2 contrast, this factor could not explain the positive relationship between Sd2 and letter identification performance. The idea of perceptual segregation has therefore remained unweakened by the present findings.

Summary

Experiment 6 demonstrated that subjects could perform both perceptual integration and perceptual segregation tasks on similar successive field stimuli. The former measure replicated the inverse Sd2 effect, whilst the latter showed that letter identification was positively related to mask duration (Sd2). It was concluded that this evidence supported the concept that was introduced in Chapter 2, namely, that each stimulus field remained perceptually segregated until the offset of the following field.

It was also demonstrated that the probability of integration was reduced if the compatibility between the visual form of S1 and the visual form of an integrated

stimulus display was low. It was tentatively proposed that this might be explained if integration was inversely related to the degree of perceptual organization that had been achieved in perceptually segregated fields. This process was conceptually linked with the hypothetical second inhibitory influence on integration that was originally introduced in Chapter 2.

A dissociation model of temporal integration was introduced in response to these findings.

Experiment 7 explored a possible loophole in the conclusions that were derived from the positive relationship between letter identification and Sd2. These conclusions would have been considerably weakened if it had been shown that the effect could be due to apparent inverse contrast between the 1st and 2nd stimulus fields (i.e. S2 brighter than S1). Very little evidence was found to support this; in fact, the strongest evidence suggested that inverse contrast was detrimental to performance. Both temporal integration and temporal segregation effects were replicated. They were both found to be robust over a wide range of S2 brightness conditions.

The results about the effects of brightness on integration were fairly inconclusive. However, it was demonstrated that this factor contributed little to performance when Sd2 was long.

CHAPTER 4: TEMPORAL INTEGRATION AND PARTIAL REPORT

Introduction

It was originally thought that partial report (PR; see Chapter 1) and temporal integration (TI) techniques (as well as other 'direct' techniques) measured similar persistence phenomena. However, evidence that this was not so gradually accumulated. One of the major reasons for this suspicion has been summed up by Coltheart (1984):

> "The main basis for the repudiation of the view that the 'direct methods' provide information about iconic memory concerned the effects of display luminance and display duration. In a variety of experiments using several of the direct methods it has been found that, as display luminance or display duration increases, the duration of visible persistence decreases. Studies that have used the partial-report technique, however, did not provide any evidence that the duration of iconic memory depended upon display luminance or display duration. This was taken as evidence that iconic memory (as studied by the partial-report technique) and visible persistence (as studied by the 'direct methods') are different processes".

Despite the empirical evidence referred to by Coltheart, his viewpoint does not feel intuitively satisfying to this writer. Indeed, the present chapter is an attempt to reconcile the differences between PR and TI and demonstrate how they may, after all, be dependent on similar processes. One basis for this intuition arises from the fact that both TI and PR techniques make use of successively presented visual fields (only PR using visual cues need be considered here) and may be that per-

formance in both tasks can be facilitated by perceptual integration. For example, Averbach and Coriell (1961) speculated that, at short SOA's, subjects were highly successful at the partial report task because they were apparently able to visually summate the target item with the probe (i.e. visual cue).

Also, Coltheart's assertion that luminance is *always* found to have a negative influence on persistence duration measured by direct techniques is not entirely solid as far as temporal integration is concerned. For example, as pointed out in Chapter 1, Eriksen and Collins (1968) obtained positive effects of luminance with TI and Di Lollo and Woods (1981) obtained little effect at all.

There is, however, less question about the negative influence of duration on TI; a number of consistent observations to this effect were discussed in Chapter 1 and these were replicated in the present thesis. Clearly, this presents a major stumbling block to reconciliation since there is no effect (or sometimes a positive effect) of array duration in PR (Di Lollo, 1978; Irwin and Yeomans, 1986; Sperling, 1960; Yeomans and Irwin, 1985).

Nevertheless, the effects of other duration parameters may be similar across both TI and PR. Regardless of which method is used, performance is inversely related to ISI. Moreover, there is some evidence to show that performance in a PR task is inversely related to the duration of a visual cue (Townsend, 1973). The visual cue (probe) is synonymous with the following field in the Eriksen and Collins paradigm and, as has been demonstrated in this thesis, this parameter is inversely re-

lated to temporal integration.

Unfortunately, Townsend's investigation fails as a convincing demonstration of the similarities between PR and TI because she used single item cuing. It is possible that the close spatial proximity of the long duration probe acted directly on the perception of the target item so as to render it, in some way, less perceptible. For the similarity to be convincing, it is necessary to demonstrate that the probe duration effect was not due to backward masking (a similar hypothesis was rejected for TI in Expt. 6); this is one of the problems under investigation in the following experiment.

Information persistence

As stated earlier, Coltheart (1980a, b) proposed that visible persistence and information persistence (iconic memory) were qualitatively different. He kept an open mind about the extent to which processes involved in visible persistence were due to peripheral (neural) activity. However, he appeared to be fairly convinced that information persistence (which is seemingly manifest only via PR techniques: see Chapter 1) may be explicable in terms of cognitive processes and hence maintain a cortical locus.

It is perhaps important to reiterate here (see also Chapter 1) that although this attitude to iconic memory (when applied to PR) has been historically favoured, the original idea that iconic memory contained only literal visual information of a precategorical nature may have been uncomfortable for the theorists who favoured a cognitive interpretation. However, more recently, the notion

that PR performance may rely on item selection from postcategorical stages has become more acceptable since some evidence for partial report superiority with postcategorical cues has recently come to light (see Coltheart, 1984 and Mewhort *et al*, 1981, 1984 for discussions on this topic).

Another reason to suppose that persistence in PR is not entirely precategorical is that mislocation (transposition) errors tend to be far more frequent than intrusion errors (Dick, 1974; Eriksen and Rohrbaugh, 1970; Irwin and Yeomans, 1986; Mewhort *et al*, 1981, 1984; Townsend, 1973; Yeomans and Irwin, 1985). The favoured argument to explain this finding is that spatial information is less robust than identity information. This, in turn, implies that the two types of information are differentially coded and clearly, the possibility that PR selection can be postcategorical supports this notion. There are, in fact, a number of different interpretations of these empirical observations (some of these were considered in Chapter 1) but the concept of differential rates of decay for qualitatively different types of stimulus information remains a central theme and is also important to the arguments presented in this chapter.

Irwin and Yeomans (1986) realized that a logical consequence of the above hypothesis would be that spatial uncertainty about items in a PR stimulus array should increase as probe delay increases. Thus, items would tend to "drift" from their original locations. This predicts that as the ISI between array and probe increases, the

error distance (Euclidean distance[1]) for transpositions should also increase. In other words, the spatial locations from which transposed items were drawn would become increasingly distant from the target location. They were also interested in the possibility that the duration of persisting spatial information might be constant and generated from stimulus onset (from Di Lollo, 1978, 1980), in which case, performance would also have been inversely related to array duration.

They tested this using a 3 x 3 stimulus array where the subject's task was to report all the items in a target row. Their results showed that most transpositions were selected from locations that were immediately adjacent to targets (i.e. a Euclidean distance of 1) and this pattern did not significantly alter with probe delay (which ranged from 0 to 500 ms). They concluded that "... the spatial layout of the stimulus array is preserved during the persistence period, as shown by ... the distribution of location errors". This conclusion must reopen speculations as to the causes of transposition errors. They further noted that array duration had no effect and concluded that visual information did not decline in availability until stimulus offset.

Dissociation in partial report

It may be that some aspects of the PR paradigm could be explained in terms of the (dissociation) hypothesis that was introduced in Chapter 3. An explanation along these lines would be unlikely to be successful if the

[1]The square root of the sum of the horizontal distance squared and the vertical distance squared.

qualitative distinction between visible and information persistence is correct. However, as pointed out earlier, there are tentative reasons to doubt the truth of this assertion for TI and PR.

As discussed in Chapter 3, the dissociation hypothesis proposes that two processes will limit integration: (1) The decay of visual persistence which probably allows visual information to begin to be lost after stimulus offset (the availability of visual information at display offset, when integration is triggered, partly determines integration performance); and (2) the tendency towards perceptual dissociation which is determined by the degree of perceptual organization in the leading (and possibly the following) field (integration performance will be inversely related to perceptual organization).

Applied to the PR paradigm, with the use of a visual cue, it might be that performance is also, in part, reliant on temporal integration processes. In this case, persistence decay and perceptual dissociation might be expected to limit performance in different ways.

Let us consider the effects of persistence decay (in isolation) first and resurrect the old idea that persistence is a globally decaying literal visual representation. According to the dissociation hypothesis, visually cued items could not be selected from an array until the termination of the following field. This is because the relative positions of the array and the probe could not be accurately determined until integration is triggered by the probe's offset. Thus, the temporal interval over which persistence must decay before a response can be

formulated must include the probe presentation period. Now, if it is assumed that visual persistence begins to decay at stimulus offset then it might be expected that there would be no effect of array duration but that errors might increase with both ISI and probe duration. The increased incidence of errors would be due to the loss of clarity and, in an ideal situation, these errors would be intrusions. Performance would be expected to deteriorate as ISI and probe delay increased but not with changes in array duration.

The effects of perceptual dissociation would be different. As pointed out in previous chapters, the probability of integration would be expected to decline as total display duration (array onset to probe offset) increased. The effect of this might be to increase relative spatial uncertainty between the array and the probe and this would result in a greater tendency to produce array-probe misalignments. Thus any lengthening of array duration, ISI and probe duration should be reflected by increases in transposition errors.

The sum effect of the above two processes should be declining PR performance as all three temporal parameters increase. On the face of it, this must be wrong since, as pointed out above, inverse array duration effects have not been obtained with PR. However, there are certain ramifications of the dissociation model that can modify its predictions in order to bring it more in line with empirical findings.

There are two common methods of obtaining PR data with the use of a visual probe. The differences are exem-

plified by that used by Averbach and Coriell (1961) as opposed to that used by Yeomans and Irwin (1985). Both methods employed an array that was displayed as a rectangular matrix consisting of more than one row of letters. However, the two methods differed in their respective report procedures. Averbach and Coriell employed a single letter report procedure (SL) where the probe cued single characters by pointing at the relevant item. In Yeomans and Irwin's procedure the probe indicated whole rows for report (termed here *full row* or FR). The dissociation model would predict that array duration effects would depend on which procedure was used.

With SL report, array-probe misalignments in either the vertical direction or the horizontal direction could give rise to transposition errors. Misalignments, and hence transposition errors, would be expected to increase with array duration (as well as with the other two temporal parameters) and therefore the original predictions of the dissociation model do not need to be modified here; performance would decline as all three temporal variable increased.

The possibility that array duration might affect PR performance with SL report has rarely been investigated. One notable exception is Di Lollo (1978) who compared 100 and 200 ms arrays where cue delay was 0 ms and did not obtain any difference between the two conditions. However, it may be that at this ISI the probability of temporal integration was not influenced by array duration. Also, he used a frame which surrounded items in order to cue single targets; it may be that this type of probe was

less likely to become misaligned with the array. Experiment 8 also investigates the effect of array duration on PR performance in SL report conditions but, in this case, a narrow bar probe, where the possibility for spatial misalignments might be greater, is used.

The effect of array duration has been investigated more thoroughly with FR report and, here again, inverse array duration effects have never been claimed (e.g. Sperling, 1960; Irwin and Yeomans, 1986; Yeomans and Irwin, 1985). However, this result might be expected via dissociation because the opportunities for array-probe misalignments to influence performance are greatly reduced. According to this hypothesis, only misalignments in the vertical dimension would result in transposition errors. Consider a 2 x 2 stimulus array. If the probability of obtaining a correct alignment were at chance level then with SL report the probability of a correct response (ignoring loss of clarity due to persistence decay) would be 0.25. However, with FR report this probability increases to 0.5. Clearly, therefore, the probability of obtaining inverse array duration effects would be less in the FR condition. If, at the same time, a longer duration array increased the perceptibility of arrays then errors due to mistaken identity may have been reduced.

There is evidence that the latter point may be true from Sperling (1960). He found a marginally positive relationship between array duration and PR performance. However, he used the FR procedure where rows were cued by means of a tone. In this case, there would be *no* opportunity for array-probe misalignments and hence transposi-

tions would not be expected to increase with array duration. At the same time, the increased exposure duration may have increased the clarity of the display and this could have been responsible for the slight improvement in performance.

It might be argued that evidence of misalignments would have been noted before now but these may have been obscured because they may not be the only source of transposition errors. In fact, a large proportion of these may be due to a plethora of reasons. For example, some transposition errors could be caused by errors of identification. Identification errors which coincidentally matched array items would be recorded as transpositions.

For the purposes of the following PR investigation, errors which are not due to hypothetical misalignments will be termed *residual* errors in order to distinguish them from *misalignment* errors. Irwin and Yeomans (1986) appear to have provided some evidence to show that this idea has value. They demonstrated that transpositions were much more likely to be selected from locations that were adjacent to targets. However, what they failed to point out, but was entirely evident from their data, was the fact that most of the excess transpositions were obtained from locations directly above or below targets rather than to either side. They used FR report conditions and, clearly, array-probe misalignments would be expected to induce this kind of error pattern.

In summary of this introduction, the dissociation hypothesis can be distinguished from perceptual drift

theories of partial report on the basis of how visual information is lost over the period of persistence. The latter propose that spatial information about an array is lost earlier than identity information and that this process begins at stimulus offset. Moreover, they do not consider the possibility that item selection from arrays would not begin until probe offset. They therefore predict that only increasing probe delay will cause deficits in performance. The concomitant errors would be caused by perceptual drift rather than loss of item identity information and hence transpositions would predominate over intrusions.

In contrast, the dissociation hypothesis proposes that there would be no specific loss of spatial information about the array itself but that there would be increasing uncertainty about the probe's position relative to the array. The tendency towards misalignment would increase with increases in array duration, probe delay and probe duration but these effects would be mainly noticeable in SL report conditions. On top of this, global persistence decay would operate to decrease display clarity during the array-probe ISI period and the probe presentation period. The resultant predictions are that performance would be inversely related to all three duration parameters for SL report but for FR report it might only be seen to be inversely related to ISI and probe duration.

One version of the perceptual drift hypothesis, that has only been briefly alluded to here, is that suggested by Di Lollo (1978). His version differs from the others

in that he proposed that spatial information about the array would begin to be lost from stimulus onset rather than offset. If this were so then performance would be expected to show an inverse relationship with array duration in both the SL and FR report modes.

Experiment 8 was a PR experiment that included both SL and FR report conditions. The probe was a visual cue that pointed to single letters. The effects of array duration (Sd1), ISI and probe duration (Sd2) were all investigated.

Di Lollo's proposal could somewhat weaken the power of this experiment to distinguish between the two classes of hypothesis (*dissociation* and *drift*) since performance deficits with increasing array duration could be accounted for by both. However, a resolution to this problem seemed possible because of the hypothetical distinction between misalignment and residual errors that has been predicted by the notion of perceptual dissociation. Certain unique patterns of transpositions would be predicted from this idea. If, instead, transpositions were partly due to loss of spatial information about the array itself then no such error distinction would be predicted. The premise and predictions of this extension to the hypothesis will be explained in detail once the general aspects of Expt. 8 have been clarified.

Experiment 8: Partial report with two report methods and three temporal variables, using a visual bar probe

Introduction

The stimulus array was a random selection of 10 letters presented in a 5 column by 2 row format. The visual probe was a narrow bar that could be positioned either directly above a letter in the top row or below one in the bottom row. In one condition, the probe cued single letter targets (SL report). In another condition (FR report) a full row was cued by the position of the probe (i.e. when the probe was above an item, the top row was cued and when it was below an item, the bottom row was cued).

Array duration (Sd1), ISI and probe duration (Sd2) were all varied over two levels. As stated above, it was expected that, with SL report, performance would be inversely related to all of these variables.

On the other hand, it was expected that the inverse Sd1 effect would be muted or not at all apparent in the FR report conditions. Assuming chance alignment of the array and the probe, the probability of correct alignment in FR conditions was 0.5 but only 0.1 in SL conditions. Of course, there was no reason to suppose that the probability of correct alignments would ever fall as low as this.

It was predicted that the inverse Sd2 effect would manifest itself in both report conditions for two reasons: (1) Integration would be triggered at probe offset

and thus array perceptibility would decrease as persistence decayed over the ISI plus the probe duration period; and (2) both the array and probe stimuli would have more time to be processed in isolation. This would increase the degree of perceptual dissociation after probe offset which, in turn, would increase the probability of array-probe misalignments and hence of transposition errors.

In contrast, drift theories that propose loss of spatial information about the array itself would predict either no inverse Sd1 effects at all (if the proposal is that information decays after stimulus offset) or inverse Sd1 effects in both SL and FR conditions (this would be predicted by Di Lollo who proposed that spatial information starts to be lost after onset). Both might expect greater performance deficits to increase with lengthening ISI but neither would predict any probe duration effect.

It was thought that the FR conditions would provide a more rigorous test of probe duration effects than Townsend (1973); most of the targets would be too spatially distant from the bar probe for backward masking (perhaps by metacontrast) to occur. However, no other explanation of a probe duration effect, in PR, has ever been offered in order to contrast against the dissociation hypothesis.

Transposition errors could be caused by loss of spatial information about the array, or by array-probe misalignments. The above predictions do not differentiate between these two causes. However, as mentioned above, they would not predict identical patterns of transposi-

tion errors.

With FR report, array-probe misalignments would sometimes cause observers to report the incorrect row. This would result in a tendency to produce vertically adjacent transposition errors (i.e. wrong row but correct column). Residual errors, on the other hand, would be equally probable in all array locations. The result would be a predominance of vertically adjacent transpositions over horizontally adjacent transpositions (i.e. correct row but in the column that was adjacent to the target). That is to say that transpositions would tend to occur with items that were directly above or below a target item rather than to either side of it.

With SL report, the transposition error pattern would be different. Array-probe misalignments could cause transpositions in both horizontal and vertical directions and, again, the probability of residual error occurrences would be the same between all item locations. Thus, there would be no reason to suppose that vertically adjacent transpositions would be more numerous than horizontally adjacent ones. Moreover, the probe would need to move over a smaller visual angle in order to create a horizontal as opposed to vertical transposition error. It may therefore be that horizontal adjacencies would predominate over vertical adjacencies.

If, on the other hand, transpositions were caused by loss of spatial information about the array itself, then there would be no reason to suppose that perceptual drift would be greater in the vertical as opposed to the horizontal direction. Horizontal and vertical adjacen-

cies, being equidistant from targets, would not be expected to differ. Furthermore the pattern of transpositions would not differ between SL and FR conditions.

Aims

1. To demonstrate the inverse Sd1, ISI and Sd2 effects in the single letter report condition.

2. To demonstrate inverse ISI and Sd2 effects in the full row report condition.

3. To differentiate the hypothetical action of array-probe misalignments from other causes of transposition error.

Method

Sd1 and Sd2 were varied between 33.33 and 100 ms. ISI was 16.67 and 100 ms. Eight temporal conditions were therefore created by factorial combination. However, the total number of conditions was double this, since the two report conditions were performed under each temporal condition. A repeated measures design was employed.

Subjects

There were eight subjects. These consisted of the experimenter and colleagues employed in the Department of Psychiatry at the Royal Free Hospital, London. Their ages ranged between 27 and 36 years. Four of them were female. All subjects had normal or corrected to normal vision. All subjects (except the experimenter) were naive about the purposes of the experiment.

Apparatus and Control of Stimuli and Timings

The apparatus in this experiment was almost identical to that used in Expts. 1 and 2. Stimuli were displayed on the PET monitor but this time only a single filter was used. This was the same type of perspex amber filter that was used in Expts. 1 and 2. Its purpose was to limit the effects of residual screen phosphorescence. Stimuli were therefore seen in sharp focus with a pinkish-white coloration.

A flat hardboard cover (painted matt black), with a 4 cm square hole cut from its centre, was placed over the display screen and flush with the filter. It was arranged so that the centre of the hole coincided with the centre of the stimulus array. The cover's purpose was to remove any gross screen reflections, whilst providing S with a full and clear view of the stimuli.

Timings were effected by counting screen refresh pulses which occurred at approximately 16.67 ms intervals. Further technical details are provided in Appendix 3.

Stimuli and display

Each array consisted of 10 upper case letters. All the letters of the alphabet were used except for the five vowels and *Y*. Array characters were randomly selected except that no letter was repeated within a trial.

Each letter stimulus was 3 mm wide (maximum) by 3.75 mm high. At the subject viewing distance, their approximate visual angles were 0.37° by 0.47°. The rows were separated by an angular gap of about 0.062° and the minimum gap between columns was 0.093°. The approximate

visual angles of the full array were 2.242° wide by 0.996° high.

The probe was approximately 0.5 mm wide by 4.25 mm high and could be positioned centrally above any letter in the top row or centrally below any letter in the bottom row. The gap between the probe and a letter was approximately 0.5 mm. Thus the angular distance between the bottom of the probe when it cued the top row and the top of the probe when it cued the bottom row was approximately 1.12°. Adjacent probe locations were separated by 0.47°.

The mean stimulus luminance was approximately 32 cd/m² (measured under the experimental lighting conditions). The experiment was conducted in a relatively light environment. This caused some screen reflection which was evenly distributed across the exposed display surface and measured to be approximately 7 cd/m². All luminance measurements were made by a Tektronix J16 digital photometer, equipped with a J6523-2 1° luminance probe.

A central fixation stimulus was briefly presented prior to each array onset. This signal looked like the letter *H* lying on its side. It was approximately 4 mm wide by 5 mm high.

Procedure

The laboratory was lighted by a hooded household 40 watt lamp. The resultant illumination was dim but bright enough to read in. The lamp was positioned so that light was evenly reflected over the 16 cm² of exposed screen surface. Subject viewing distance was 460 mm.

The instructions were given verbally to S and accompanied by a number of informal practice trials where

Sd1, ISI and Sd2 were all 16.67 ms. S was provided with full feedback on all of these trials. The instructions were as follows:

> "When you are ready to begin a trial, press your trigger button. You will then see the central fixation symbol. Please fixate your eyes on this location and maintain the direction of your gaze until the full display has terminated. After the letter array and probe have been presented, say clearly out loud which letter you think the probe was pointing at. If you are not sure about any of the letters please guess. Please keep your head firmly in the headrest during each trial."

This procedure was then repeated for FR practice and the instructions were altered accordingly.

S's each undertook 16 blocks of 30 trials (the first 10 trials in a block were always for practice purposes but S's were only told that the 1st five were practice). Temporal and report conditions remained constant within blocks. The 1st block was always the SL report condition. These report blocks were alternated so that a SL report block was always followed by a FR report block in the same temporal conditions. Temporal conditions between report block pairs were randomized on a Latin square design.

S's were informed which report method to use at the beginning of each block. Trials proceeded as follows:

S triggered a trial with the hand-held button. The fixation stimulus then appeared for 0.5 secs followed by a blank (dark) screen for a further 1 sec. The array then appeared for its designated duration followed by a dark ISI period, followed by the probe presentation. S then provided a verbal response which was written down by E. This procedure varied slightly on the 1st five trials of

a block in that after S had responded, the original array and correctly located probe reappeared on the screen together. This was done in order to provide S with feedback for practice.

Array presentations and probe locations were randomized with the constraint that each of the 10 possible probe locations was used twice over the last 20 trials in a block.

It was noted by E that subjects almost always reported items in a left to right fashion, in the FR report condition. In rare exceptions they did not provide all five responses at once but reported a blank in the left to right read-out and supplied the missing response afterwards.

Results and Discussion

All scores were converted to percentages. The data from FR report conditions were separated into *direct* and *indirect* target. The former related to items that were directly pointed to by the probe and the latter were the remaining targets in a row. Table 4.1. shows the mean correct scores for the SL report condition. Tables 4.2 and 4.3 show mean correct scores in the FR report conditions for indirect and direct targets respectively. Mean correct scores for SL and FR report modes are also depicted in graph form in Figures 4.1 and 4.4, respectively.

Single Letter Report

The main effects of the three temporal factors, applied to correct scores in SL report, were all highly significant in a 3 way ANOVA (F_{sd1}=88.176; df=1, 7;

$p<.001$: $F_{ISI}=49.134$; df=1, 7; $p<.001$: $F_{Sd2}=19.368$; df=1, 7; $p<.01$). All these temporal variables were inversely related to performance. No significant interactions were noted. However, the graphical evidence (Fig. 4.1) does suggest that the Sd1 effect declined when either ISI or Sd2 were long (the Sd1xISI and Sd1xSd2 interactions tended towards significance, see page 328). The Sd1 effect was entirely absent when both ISI and Sd2 were long.

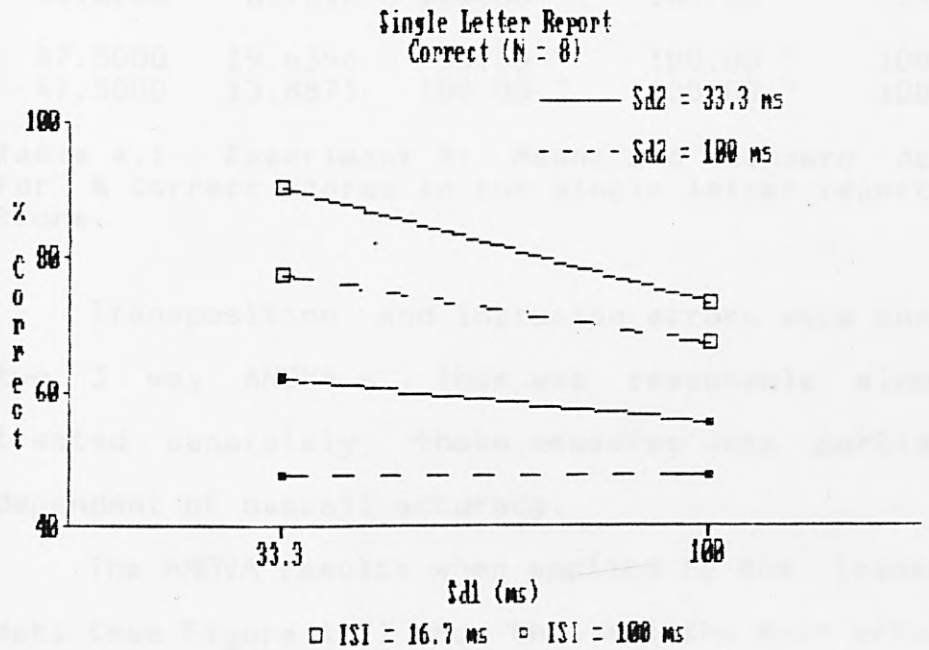


Figure 4.1 - Experiment 8: Graph of mean % Correct scores in the single letter report conditions.

The inverse Sd1 effect supports the predictions made by both the dissociation hypothesis and Di Lollo's version of perceptual drift. The negative ISI function is to be expected from any hypothesis which includes the idea of persistence decay and, clearly, this result holds no surprises. However, the inverse probe effect only relates to the ideas inherent to dissociation. Caution needs to be exercised in interpreting the latter result since

probes were close to targets and there may therefore have been an element of masking here; it is possible that the long duration probes were more masking than short ones.

% Correct	Std.Dev.	Sd1	ISI	Sd2
90.0000	9.2582	33.33 ms	16.67 ms	33.33 ms
73.1250	18.3103	100.00 "	16.67 "	33.33 "
77.5000	14.3925	33.33 "	16.67 "	100.00 "
67.5000	15.3530	100.00 "	16.67 "	100.00 "
61.8750	17.9160	33.33 "	100.00 "	33.33 "
55.6250	6.7810	100.00 "	100.00 "	33.33 "
47.5000	19.6396	33.33 "	100.00 "	100.00 "
47.5000	13.8873	100.00 "	100.00 "	100.00 "

Table 4.1 - Experiment 8: Means and standard deviations for % Correct scores in the single letter report conditions.

Transposition and intrusion errors were analysed in two 3 way ANOVA's. This was reasonable since, when treated separately, these measures were partially independent of overall accuracy.

The ANOVA results when applied to the transposition data (see Figure 4.2) show that all the main effects were significant (F_{Sd1}=8.19; df=1, 7; p<.025: F_{ISI}=41.195; df=1, 7; p<.001: F_{Sd2}=12.553; df=1, 7; p<.01). Thus, increasing any of the duration variables led to increasing numbers of transposition errors. There were no significant interactions. However, the graph indicates that the main contribution to the Sd1 effect occurred when both ISI and Sd2 were short.

This result again supports dissociation and Di Lollo's version of perceptual drift. Misalignments would have increased with Sd1 and this, in turn, would have in-

creased transpositions. Since dissociation, and hence array-probe misalignments, would also increase with increasing ISI and Sd2, the positive relationships between transpositions and these two variables are also accounted for here.

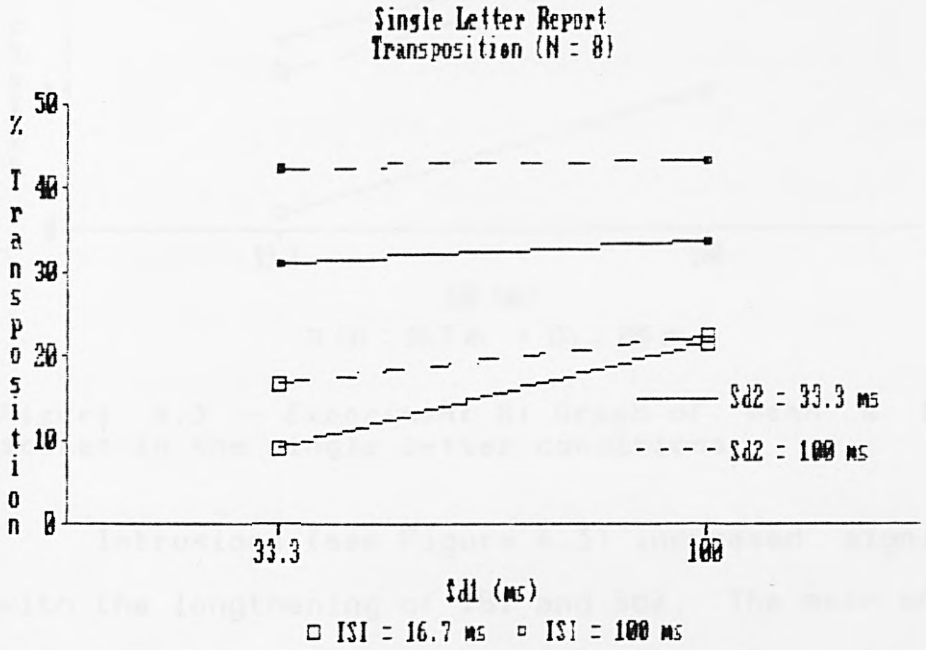


Figure 4.2 - Experiment 8: Graph of mean % Transposition scores in the single letter report conditions.

Alternatively, if spatial information, in the array, was being lost after stimulus onset then perceptual drift, and hence transpositions, would also increase with increasing Sd1 and ISI. However, since perceptual segregation is not hypothesized, and hence there is no mechanism for item selection to be delayed until probe offset, it is difficult to see how drift would explain the rise in transpositions which accompanied increases in probe duration. Presumably subjects would make their selections from arrays at some time after probe onset but there would be no reason to suppose that probe duration

would influence their selection latencies

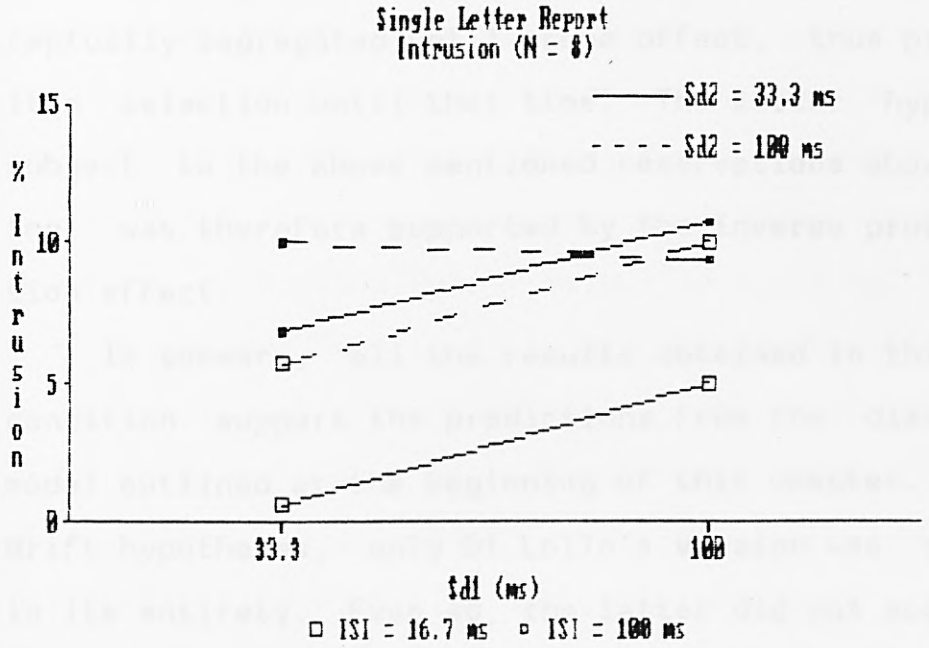


Figure 4.3 - Experiment 8: Graph of mean % Intrusion scores in the single letter conditions.

Intrusions (see Figure 4.3) increased significantly with the lengthening of ISI and Sd2. The main effect of Sd1 was not significant (F_{Sd1}=3.515; df=1, 7; not significant: F_{ISI}=26.198; df=1, 7; p<.01: F_{Sd2}=6.333; df=1, 7; p<.05). There were no significant interactions.

The dissociation model and both versions of drift would not expect array duration to negatively influence intrusions and this did not happen. For dissociation, there is no global loss of information until after stimulus offset. Drift hypotheses would agree that identity codes should remain stable and unaffected by array duration but some small loss might be expected with increasing ISI.

However, only the dissociation model predicted that persistence decay and perceptual dissociation would

continue to influence performance until probe offset. This is because the array and the probe would remain perceptually segregated until probe offset, thus preventing item selection until that time. The latter hypothesis, subject to the above mentioned reservations about masking, was therefore supported by the inverse probe duration effect.

In summary, all the results obtained in this report condition support the predictions from the dissociation model outlined at the beginning of this chapter. Of the drift hypotheses, only Di Lollo's version was supported in its entirety. Even so, the latter did not account for probe duration effects. As mentioned above, caution needs to be applied to these results since the target items and probe were always spatially proximal. It is possible that these two stimuli interfered with each other in processing (perhaps via meta- and paracontrast mechanisms) to produce this particular pattern of results.

The following paragraphs discuss the conclusions that might be drawn from the single letter report conditions:

The impairment in performance due to lengthening Sd1 was thought to be due to either: (1) misalignment between the array and probe, due to incomplete temporal integration but with no differential loss of visual information about an array; or (2) loss of spatial information about the items in the array (hence resulting in perceptual drift). If the second explanation were correct then this would vindicate Di Lollo (1978) in his proposal that persistence is generated at stimulus onset and that spatial

codes are less permanent than identity codes.

These results appear to support both hypotheses but the inverse effect of probe duration on correct identifications was only predicted by *dissociation*. According to this notion, persistence is a literal representation of the stimulus array and this begins to decay from offset. However, successful target selection would not occur until stimulus offset so that persistence decay would be evident over the probe presentation period as well as the probe delay period. The pattern of intrusion errors supports these ideas since intrusions were only significantly related to ISI and probe duration.

The significantly positive relationship between transpositions and Sd1 might indicate that array-probe misalignments were more probable at the long array durations. It was seen that this tendency continued to increase over the ISI and probe presentation periods (as indicated by the significant increase in transpositions with ISI and Sd2). This might have been evidence of progressive array-probe misalignments but this possibility will be considered in more depth later.

Full Row Report

As mentioned above, the FR results were sifted into directly and indirectly targeted data (% Correct scores are given in Tables 4.2 and 4.3 and Fig. 4.4).

A 3 way ANOVA, computed for indirect (% Correct) data, confirmed that there was no significant effect of Sd1 but that performance declined significantly when both ISI and Sd2 increased (see Table 4.4). There were no significant interactions.

Indirect targets

% Correct	Std.Dev.	Sd1	ISI	Sd2
66.2500	12.8695	33.33 ms	16.67 ms	33.33 ms
65.3125	8.0109	100.00 "	16.67 "	33.33 "
60.4688	10.2630	33.33 "	16.67 "	100.00 "
62.0313	11.7629	100.00 "	16.67 "	100.00 "
55.3125	12.6023	33.33 "	100.00 "	33.33 "
53.5938	8.3569	100.00 "	100.00 "	33.33 "
50.7813	11.9511	33.33 "	100.00 "	100.00 "
51.8750	10.7321	100.00 "	100.00 "	100.00 "

Table 4.2 - Experiment 8: Means and standard deviations for % Correct scores in the full row report conditions on indirect targets.

Direct targets

% Correct	Std.Dev.	Sd1	ISI	Sd2
78.1250	11.9336	33.33 ms	16.67 ms	33.33 ms
65.6250	10.5009	100.00 "	16.67 "	33.33 "
65.0000	12.5357	33.33 "	16.67 "	100.00 "
58.7500	10.2644	100.00 "	16.67 "	100.00 "
52.5000	20.8738	33.33 "	100.00 "	33.33 "
54.3750	16.3527	100.00 "	100.00 "	33.33 "
46.8750	13.3463	33.33 "	100.00 "	100.00 "
48.7500	16.2019	100.00 "	100.00 "	100.00 "

Table 4.3 - Experiment 8: Means and standard deviations for % Correct scores in the full row report condition on direct targets.

The lack of array duration effects was predicted by both dissociation and one version of drift. The former, because this factor would only affect misalignments but for the reasons discussed earlier this influence not expected to influence overall performance to any great extent in FR conditions. One version of drift, where information was not expected to be lost until after array offset, was also supported here. However, it is interest-

ing to note that this is not the version that was supported by SL results.

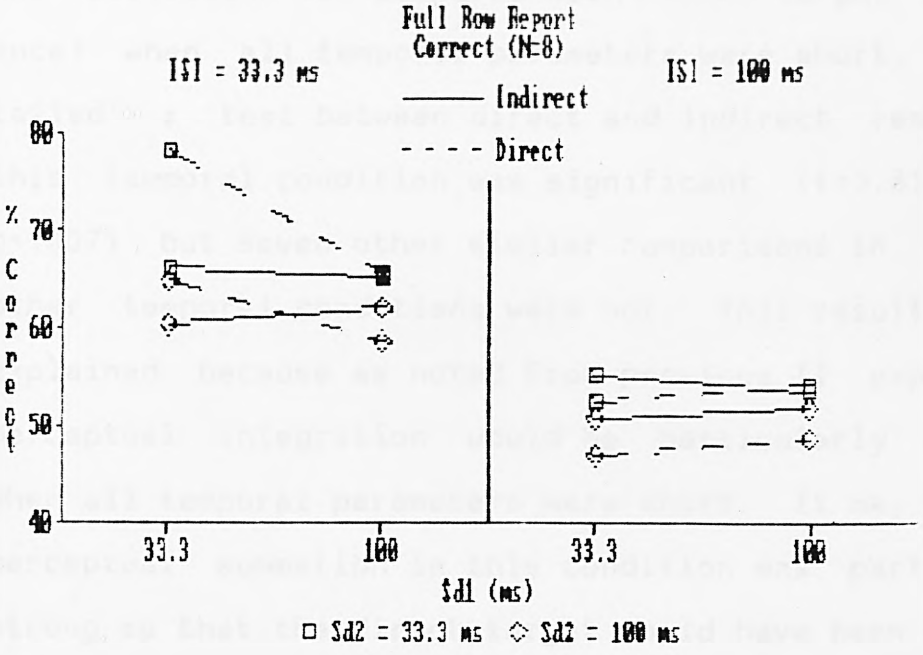


Figure 4.4 - Experiment 8: Graph of mean % Correct scores in the full row report conditions.

The probe duration effect helps to confirm that target selection did not begin until probe offset. It is extremely unlikely that masking could have been involved since indirect targets were not near the probe and therefore were immune to any direct perceptual influence by it.

A 3 way ANOVA for direct (Correct) data (see Table 4.5) tells a slightly different story however. There again, only the main effects of ISI and Sd2 were significant but there was a significant interaction between Sd1 and ISI. This arose because Sd1 *did* have an inverse effect when ISI was 33.33 ms, particularly when Sd2 was short. There was no evidence of the Sd1 effect when ISI was 100 ms.

The evidence for inverse array duration effects here was unexpected although not altogether surprising. It can be seen from Fig. 4.4 that direct target performance was facilitated (as compared with indirect target performance) when all temporal parameters were short. A 'two tailed' *t* test between direct and indirect results in this temporal condition was significant (t=3.81; df=7; p<.007) but seven other similar comparisons in all the other temporal conditions were not. This result can be explained because as noted from previous TI experiments perceptual integration would be particularly probable when all temporal parameters were short. It may be that perceptual summation in this condition was particularly strong so that the direct target would have been selected prior to other indirect targets. Array-probe misalignment, however, would increase with increasing duration parameters. This would increase lateral misalignments and these would be expected to remove the performance advantage of direct targets.

Indirect Targets
(Correct scores)

SOURCE	Df.	F	p
Sd1	1, 7	0.000	n.s.
ISI	1, 7	105.433	<.001
Sd2	1, 7	6.246	<.05
Sd1xISI	1, 7	0.054	n.s.
Sd1xSd2	1, 7	1.070	n.s.
ISIxSd2	1, 7	0.248	n.s.
Sd1xISIxSd2	1, 7	0.002	n.s.

Table 4.4 - Experiment 8: Results of 3 way ANOVA on % Correct scores with indirect targets (full row report).

Direct Targets
(Correct scores)

SOURCE	df.	F	p
Sd1	1, 7	3.500	n.s.
ISI	1, 7	43.018	<.001
Sd2	1, 7	22.906	<.001
Sd1xISI	1, 7	11.118	<.025
Sd1xSd2	1, 7	0.845	n.s.
ISIxSd2	1, 7	0.896	n.s.
Sd1xISIxSd2	1, 7	0.159	n.s.

Table 4.5 - Experiment 8: Results of 3 way ANOVA on % Correct scores with direct targets (full row report).

There was no evidence that indirect target transpositions (see Fig. 4.5) were influenced by array duration. In a 3 way ANOVA, only the main effect of ISI was significant (F_{ISI}=34.402; df=1, 7; p<.001). There were no significant interactions.

The failure to obtain the probe duration effect for indirect target transpositions can be explained on the grounds that misalignments would not strongly influence transpositions in FR for the previously discussed reason that only vertical misalignments would be important. Nevertheless, the trend of increasing transpositions with increasing probe duration was still evident in the mean data (See Fig. 4.5). With this explanation, however, it is difficult to see why transpositions should have increased so significantly with ISI.

Transpositions of direct targets (see Fig. 4.5) appear to show some evidence of an interaction between Sd1 and ISI, in that these scores did appear to increase as Sd1 lengthened when ISI was short. In a 3 way ANOVA, however, there was no significance in either the main effect

of Sd1 or in any of its interactions. On the other hand increases in both ISI and probe duration did significantly increase the probability of transpositions (F_{ISI}= 8.22; df=1, 7; p<.001: F_{Sd2}=8.566; df=1, 7; p<.001). There were no significant interactions.

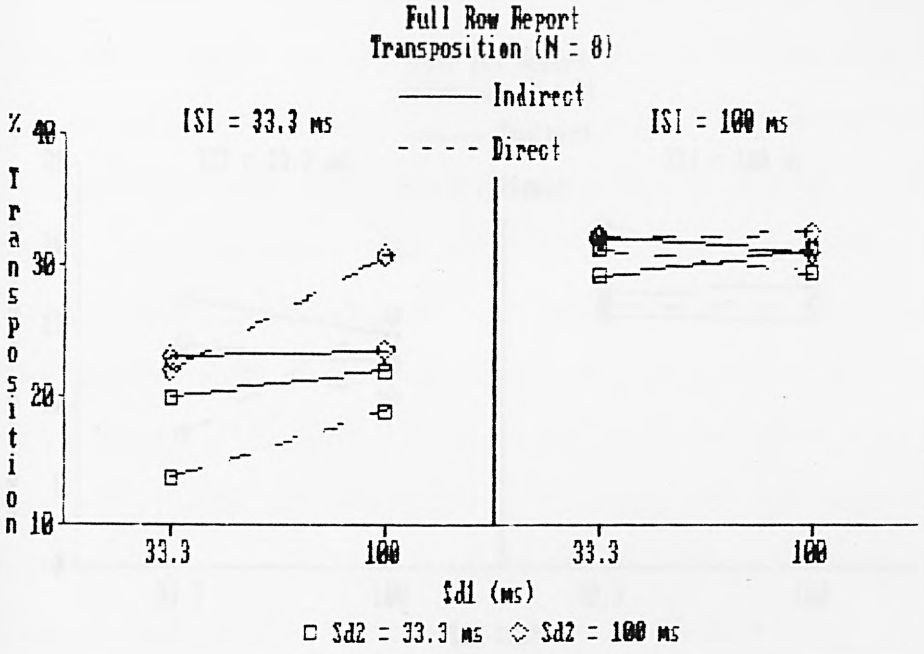


Figure 4.5 - Experiment 8: Graph of mean % Transposition scores for direct and indirect targets in the full row report conditions.

Intrusion data for both indirect and direct targets (see Fig. 4.6) gave no significant main effects or interactions in two 3 way ANOVA computations. The mean data, however, do seem to indicate a marginal decline of intrusion errors of indirect targets with increasing array duration when ISI was short.

The failure to obtain any significant effects for intrusion data might support drift hypotheses since they expect identity codes to remain robust and hence intrusion errors would not vary with changes in duration. How-

ever, all the trends expected by dissociation, with changes in ISI and probe duration, were still apparent in the mean intrusion data of indirect targets (see Fig. 4.6). Thus, although this was not significant, intrusions did appear to increase with increases in ISI and probe duration.

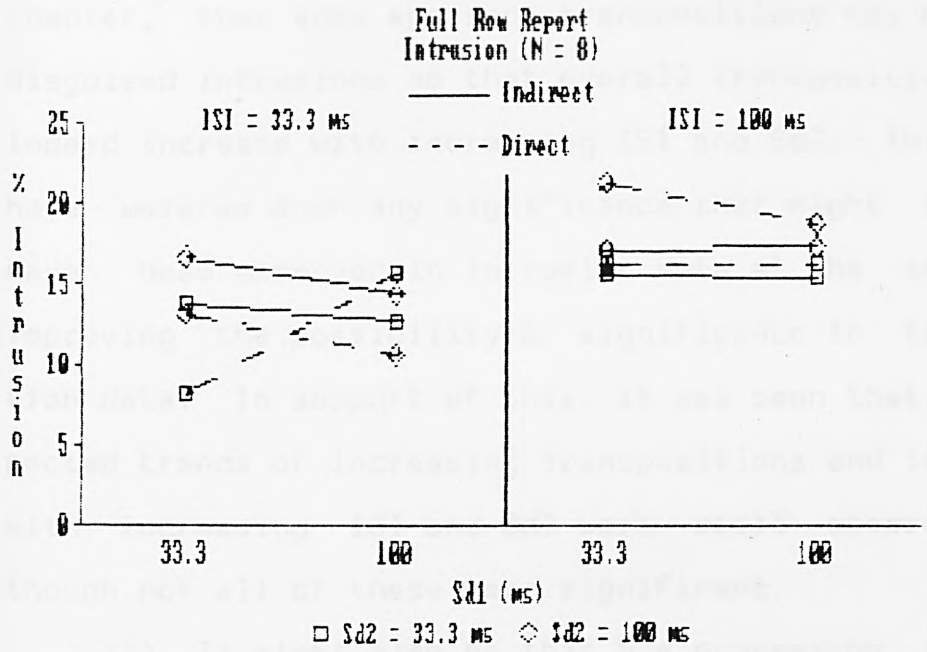


Figure 4.6 - Experiment 8: Graph of mean % Intrusion scores for direct and indirect targets in the full row report conditions.

The analyses of transposition and intrusion error patterns was not so supportive of the dissociation hypothesis as it was for SL report. However, in view of the fact that overall performance, and hence errors as a whole, did entirely support dissociation it may be that the particular error patterns found here were not antagonistic to the general concept. There are two reasons why this might be so:

(1) Ideally, it might have been expected that in-

creases in intrusion errors rather than transposition errors would have been the main source of error variance. This is because array-probe misalignments would not be expected to greatly influence performance with indirect targets and hence transposition errors would not be expected to vary with varying duration parameters. However, it might be, as pointed out in the introduction to this chapter, that some apparent transpositions may have been disguised intrusions so that overall transpositions might indeed increase with increasing ISI and Sd2. This would have *watered down* any significance that might otherwise have been observed in intrusion data at the same time improving the possibility of significance in transposition data. In support of this, it was seen that the expected trends of increasing transpositions and intrusions with increasing ISI and Sd2 were still observed even though not all of these were significant.

(2) It might also be that S's processing load was particularly high in the FR report conditions and that this induced errors at both array and target visual processing and response selection stages. It has been shown that 5 letters is around the maximum that can be reported even in full report experiments (i.e. when the task is to report as many letters as possible from an array: see Sperling, 1960). Errors due to processing load would not necessarily be responsive to temporal conditions and this may well have obscured other potential error effects.

In conclusion, the predictions of the dissociation hypothesis were largely supported by performance in this (FR) report mode. With indirect targets, performance was

only inversely related to probe delay and probe duration and this effect might have been mainly due to global persistence decay over the sum of this period. As pointed out earlier, the probe duration result was extremely unlikely to have been caused by backward masking.

Although the inverse array duration effect with direct targets was unexpected, it could be explained in terms of TI where perceptual summation may have been strong when temporal parameters were short.

The lack of array duration effects was also predicted by those drift theories which state that persisting spatial information begins to be lost from stimulus offset. However, as with SL report, they have difficulty dealing with probe duration effects.

Di Lollo's proposal that spatial information about arrays begins to be lost after onset was not supported here. Even though there was some evidence of an inverse relationship between array duration and direct targets, his hypothesis could only have been supported if this relationship had held with indirect targets as well; as was seen, this did not happen.

Patterns of transpositions

The patterns of correct scores and transpositions at each array location, for FR data, are shown in Table 4.6 (these results were pooled across all temporal conditions). As can be seen, correct responses were most probable in the far left array position and this declines as the target location moves right (the exception is array column 5 where correct scores were slightly greater than in column 4). As mentioned previously, S's usually re-

sponded in a left to right fashion and it seems possible that the pattern of scores reflects this strategy.

Full row report

Target location: x - - - - / - - - - -					- - - - - / x - - - -				
86.2	0.0	0.3	0.3	0.3	6.1	0.8	0.3	0.6	0.3
8.4	0.5	0.5	0.6	0.2	*86.4*	1.4	0.8	0.5	0.0
- x - - - / - - - - -					- - - - - / - x - - -				
0.6	*81.6*	2.7	1.3	0.2	0.8	7.3	0.8	0.9	0.5
1.4	5.5	0.3	0.6	0.6	1.7	*78.3*	1.9	1.3	0.6
- - x - - / - - - - -					- - - - - / - - x - -				
0.5	3.6	*74.7*	1.9	2.7	1.3	2.8	6.3	3.1	1.4
0.9	1.4	4.2	2.3	1.6	0.3	2.3	*70.5*	2.2	1.9
- - - x - / - - - - -					- - - - - / - - - x -				
0.9	1.4	3.0	*23.0*	5.9	4.8	5.6	7.0	7.5	4.2
5.2	7.0	7.8	8.8	6.1	0.8	1.6	4.1	*27.7*	6.6
- - - - x / - - - - -					- - - - - / - - - - x				
1.9	1.1	1.4	8.9	*24.2*	3.3	5.0	4.8	4.2	8.9
3.8	5.9	5.0	6.3	12.5	0.9	2.8	1.9	7.5	*30.6*

Table 4.6 - Experiment 8: Distribution of percent correct reports and percent transposition errors in the full row report conditions. These results have been pooled across all temporal conditions. Each location in the 5x2 letter array is depicted. The target location is indicated by the *x* above each response matrix and the italicized numbers indicate the percent correct scores.

Transpositions were more likely to be selected from locations that were close to targets. It is particularly interesting to note that vertically adjacent transpositions (i.e. wrong row but correct column) were always more numerous than transpositions in any single horizontally adjacent location (i.e. correct row but adjacent column).

This is the pattern of results that might be expected if some transposition errors were caused by a misalignment between the probe and the array. As dis-

cussed earlier, some vertical array-probe misalignments might induce subjects to select the wrong row for report but small horizontal shifts would be irrelevant in this respect. A number of transpositions would also be due to residual errors. The probability of this type of error occurring would not be expected to differ between any of the locations positioned adjacent to targets. Thus a tendency towards misalignment might have been sufficient to produce the extra number of transpositions in vertically adjacent locations.

With SL report, the pattern of transpositions (see Table 4.7) was different. There was no obvious tendency for the number of vertically adjacent transpositions to be greater than the number of horizontal adjacencies. This pattern would be expected because there is no *a priori* reason why array-probe misalignments would be greater in the vertical as opposed to the horizontal direction, in this report mode. Moreover, if residual errors were equally likely to occur in all adjacent locations, all adjacent transpositions would be likely to reflect similar proportions of residual and misalignment errors.

Data for SL report showed a different pattern of correct responses to FR. This time the greatest numbers of correct scores were made in the central array locations and they declined as targets became more distant from these positions. This finding reinforces the earlier argument about patterns of correct scores in FR report. If they had been caused by basic differences in the perceptibility of letters at different array locations, then

a similar pattern would be expected in SL report. The fact that this was not so suggests that the pattern of correct scores was task specific.

Single letter report

Target location: x - - - - / - - - - -					- - - - - / x - - - -				
56.3	7.8	0.0	0.8	0.0	12.5	0.8	0.8	0.8	0.0
14.1	3.9	4.7	2.3	0.0	60.2	14.1	1.6	1.6	0.8
- x - - - / - - - - -					- - - - - / - x - - -				
3.1	65.6	6.3	2.3	0.8	1.6	2.3	2.3	0.8	2.3
7.0	4.7	0.8	0.0	0.8	4.7	76.6	2.3	3.9	0.8
- - x - - / - - - - -					- - - - - / - - x - -				
0.8	3.1	82.8	3.9	0.8	0.8	0.8	2.3	0.8	0.0
0.0	1.6	3.1	0.0	1.6	1.6	2.3	87.5	0.8	0.0
- - - x - / - - - - -					- - - - - / - - - x -				
1.6	1.6	11.7	58.6	2.3	0.0	0.8	1.6	5.5	0.0
0.8	1.6	1.6	7.0	3.1	0.0	0.8	12.5	69.5	3.1
- - - - x / - - - - -					- - - - - / - - - - x				
2.3	2.3	2.3	5.5	43.8	0.8	1.6	2.3	3.9	14.1
5.5	3.1	1.6	3.1	18.0	0.8	0.8	0.8	14.8	50.0

Table 4.7 - Experiment 8: Distribution of percent correct reports and percent transposition errors in the single letter report conditions. These results have been pooled across all temporal conditions. Each location in the 5x2 letter array is depicted. The target location is indicated by the *x* above each response matrix and the italicized numbers indicate the percent correct scores.

The effects of temporal conditions on horizontally and vertically adjacent transpositions in FR report (direct and indirect data were pooled) are shown in Figure 4.7. It is only in the four temporal conditions where ISI was long that vertical transpositions are clearly more numerous than horizontal ones. However, differences between horizontal and vertical transpositions were undervalued because there were 1.6 times as many opportunities

for horizontal adjacencies to occur by chance, as compared to vertical adjacencies. Thus, if the distribution of adjacent transpositions had been random, mislocations would have tended to accumulate in the horizontal locations but, as can be seen, there was either little difference or the reverse of this was true.

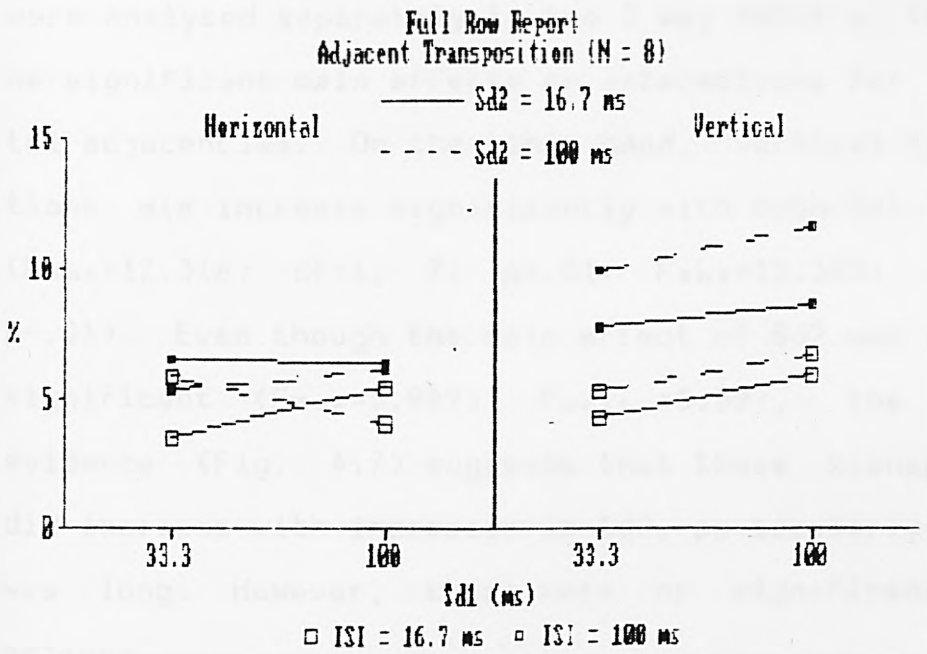


Figure 4.7 - Experiment 8: Graph of mean % Horizontally Adjacent errors (left graph) and % Vertically Adjacent errors (right graph) in FR report conditions.

One further ramification of the dissociation hypothesis was that transposition errors, which may have been due to array-probe misalignments, would be positively related to all three temporal variables. This was predicted because the likelihood of the array and the probe becoming perceptually dissociated would increase with increasing total display duration. On the other hand, there was no reason to suppose that residual errors would be consistently sensitive to all of these temporal factors.

Horizontal adjacencies (in FR) could only consist of residual errors, while vertical adjacencies would reflect both residual and misalignment errors. In this case it would be expected that only vertical adjacencies would be positively related to array duration, probe delay and probe duration.

The two kinds of adjacent transpositions (for FR) were analysed separately in two 3 way ANOVA's. There were no significant main effects or interactions for horizontal adjacencies. On the other hand, vertical transpositions *did* increase significantly with both Sd1 and ISI (F_{Sd1}=12.316; df=1, 7; p<.01: F_{ISI}=12.385; df=1, 7; p<.01). Even though the main effect of Sd2 was not quite significant (F_{Sd2}=3.999; $F_{crit.}$=5.59), the graphic evidence (Fig. 4.7) suggests that these transpositions did increase with increases in Sd2, particularly when ISI was long. However, there were no significant interactions.

In summary, three pieces of converging evidence given by patterns of transposition errors support the notion, supplied by the dissociation hypothesis, that some errors were caused by perceptual misalignments between the array and the probe:

(1) Two types of transposition were indicated by the different patterns of horizontally and vertically adjacent transposition errors in FR report conditions. There was an overall greater number of transposed responses from vertically adjacent locations than there was from single horizontally adjacent locations. This would be expected because array-probe misalignments in FR could only

cause the wrong row to be reported. They would not lead to items in the same row becoming transposed. The probability of residual error occurrences (the other hypothetical type of transposition) was the same across all item locations so that their presence would not be expected to influence this particular observation. However, they might well obscure direct observations of array-probe misalignments if less stringent analysis procedures are used.

The contrasting perceptual drift theories, which state that loss of spatial information about the array itself is responsible for transposition errors, were not supported in FR. They predicted no difference between horizontal and vertical adjacencies because the probability of items becoming transposed would depend on their distances from targets regardless of their row positions.

(2) Patterns of horizontal and vertical adjacencies were different between FR and SL report conditions. This is again to be expected because array-probe misalignments would cause transpositions in both horizontal and vertical directions with SL report modes but not with FR report modes. Thus, no differentiation between horizontal and vertical adjacencies would be predicted in SL conditions and none were found.

Drift theories cannot account for these differences between SL and FR conditions because, as mentioned above, they would not predict any differentiation between horizontal and vertical adjacencies at all.

(3) Misalignment errors (exemplified by vertically adjacent transpositions in FR) increased significantly

with array duration and probe delay and this trend was continued (although not quite significantly) for probe duration. This was predicted by the dissociation hypothesis. Misalignment errors were not expected to occur in horizontally adjacent locations with FR and, indeed, these transpositions did not give rise to significant relationships with any of the independent temporal variables.

The differences in the way that horizontal and vertical adjacencies responded to temporal variations reinforces the idea that there may be at least two types of transposition error and that one of these (misalignment error) is due to the perceptual dissociation of successively presented stimuli.

Conclusions

The findings in this experiment have largely supported the predictions that were generated by the dissociation hypothesis. There were three results in particular that help to confirm this:

(1) The inverse Sd2 effect was obtained even without spatial proximity between target items and the bar probe. The removal of any possibility of masking effects favoured the idea that selection from the stimulus array occurred after probe offset.

(2) The inverse Sd1 effect on direct targets (at short ISI's, in FR report) was thought to be due to the high probability of temporal integration when ISI was short. This, in turn, suggested that the inverse array duration effects, which were obtained in the SL report conditions, were generated by similar processes. However,

since the inverse array duration effect was absent with indirect targets, loss of persisting information was unlikely to explain any of these results. Instead, the influence of array duration could be better explained by a perceptual dissociation between array and probe (see below).

(3) Transposition errors could be differentiated into misalignment and residual errors where only the former were positively related to all three temporal parameters. Moreover, differences in the distribution of transposition errors, depending on report mode, helped to confirm this. These error patterns could be explained if perceptual dissociation, between the array and the probe, became progressively greater as array duration, probe delay and probe duration increased. Declining integration, due to perceptual dissociation, might have increased the probability of array-probe misalignments.

The alternative hypothesis was that decreasing performance is caused by the loss of spatial information from array persistence. There were two incompatible versions of this *drift* hypothesis, neither of which were consistent with all the results that were generated by the present experiment.

One version proposed that spatial information begins to be lost soon after stimulus onset and hence predicted that performance would be inversely related to array duration: This was compatible with the results from SL conditions and direct targets in FR but not with data about indirect targets.

The other version of perceptual drift proposed that

spatial information would not begin to decay until after stimulus offset: This idea was only supported with indirect targets.

Neither version of the drift hypothesis could explain the inverse probe duration effects. Moreover, neither of them would have predicted the particular patterns of transposition errors that were found here.

In conclusion, therefore, it can be stated that PR performance (where visual probes are employed) involves a number of similar processes to temporal integration tasks. There is no evidence that the kind of visual persistence which can be inferred from TI studies is any different from that which is implicated in PR.

The experiments reported in Chapters 2 and 3 were unable to confirm absolutely that persistence begins to decay only after stimulus offset. However, the present study has supported the notion that this process begins at offset.

Summary

It was hypothesized at the beginning of the chapter that partial report (with visual cuing) could be explained in terms of previous findings about TI. The major objection to this was that inverse array duration effects had never been obtained with spatial cues in PR. However, it was pointed out that according to the dissociation hypothesis (developed in Chapter 3) inverse array duration effects would only be expected when single array items were cued. It was therefore speculated that these effects have never been found because most investigations of

array duration have not utilized this particular report mode.

Experiment 8 used two different response methods with PR to show that inverse array duration effects could be obtained under certain conditions with particular targets. It was shown, however, that the influence of this temporal parameter was not due to persistence decay. In addition, inverse ISI and probe duration effects were found and it was hypothesized that these functions were only partly due to persistence decay. The latter finding was particularly supportive of the dissociation hypothesis which was developed in Chapters 2 and 3.

Analyses of error patterns indicated that two types of transposition errors could be inferred. These were termed *misalignment* and *residual* errors. It was demonstrated that the former error type was caused by array-probe misalignments. Its existence was held to support the notion that a similar process of perceptual dissociation was responsible for the temporal effects found with both PR and TI techniques.

The dissociation hypothesis was compared with two competing theories of perceptual drift but only the claims of the former were universally supported by the data.

It was finally concluded that visual persistence begins to decay from stimulus offset and that this was probably also the case with tasks involving the Eriksen and Collins paradigm.

CHAPTER 5: REVIEW, CONCLUSIONS AND DISCUSSION

5.1 Review

Chapter 1 introduced the concept of visual persistence and various reasons for inferring its existence were discussed.

A number of different experimental techniques for measuring visual persistence were considered. These were categorized into *direct* and *indirect* techniques after Coltheart (1980a, b). According to him, indirect techniques are exemplified by partial report methods and measure information persistence. Direct techniques, he supposed, measure only visible persistence; seven different techniques including the Eriksen and Collins paradigm, were discussed.

The main argument for supposing that this distinction might reflect real processes was that direct techniques tend to show that persistence is inversely related to stimulus duration and intensity (where stimulus duration is less than a critical duration of approximately 100 ms). Indirect techniques, on the other hand, either show a slightly positive relationship between performance and array duration and intensity or no effects at all.

It was pointed out, however, that not all results from direct techniques have always been in total accord. Generally, inverse duration effects are robust (although, even here, there have been claims for positive relation-

ships) but stimulus intensity effects seemed to vary between some methods. Persistence duration appeared to be inversely related to stimulus energy (i.e. intensity x duration) with *judgements of synchrony;* changes in stimulus duration did not affect persistence as long as intensity was adjusted to keep overall energy constant. However, with *temporal integration of form parts,* persistence duration often appeared to be inversely related to stimulus duration even though stimuli were equated for brightness (and therefore had approximately equivalent energies).

Temporal integration techniques were discussed in some depth and it was tentatively suggested that there was some evidence to show an inverse relationship between performance and following field duration. It was thought that this might indicate that the processes involved in this type of task were more complex than hitherto supposed.

The chapter concluded by discussing some current ideas about persistence processes. Three models, in particular, were discussed. One of these (Campbell and Mewhort, 1980; Mewhort *et al* 1981; Mewhort *et al* 1984) was mainly concerned with partial report and postulated the existence of a precategorical "feature" buffer and a postcategorical "character" buffer which could retain some spatial codes. Information was considered to be lost from these buffers, in various ways, after stimulus offset. The argument against this model was that there seemed to be no obvious reason why information in a postcategorical buffer, which is able to store some spa-

tially coded information for periods that are independent of stimulus duration, should not be utilized in temporal integration tasks. Evidence from direct methods do not support this idea.

Another model (Yeomans and Irwin, 1985; Irwin and Yeomans, 1986) proposed that a "sensory representation" mediated performance in direct tasks. They implied that visual information represented here might begin to be lost from stimulus onset. Partial report, on the other hand, is partly mediated by a "visual analogue" where the duration of persisting information is independent of stimulus duration. The problem with this explanation was similar to the objection about Mewhort's model. There seemed to be no *a priori* reason why a temporal integration task cannot make use of feature information in the visual analogue. Yet this was clearly contraindicated in Irwin and Yeoman's model.

The third model (Di Lollo, 1978, 1980) purported to be a general explanation for persistence phenomena. It maintained a distinction between visible and information persistence and argued that spatial information in visible persistence begins to be lost after stimulus onset. However, it did not argue that visible persistence was irrelevant to performance in partial report tasks. It therefore fell down in its inability to explain why partial report performance is apparently not inversely related to array duration and luminance.

A minor variation of Eriksen and Collins's temporal integration technique, where letter parts were used, was taken as the starting point for the empirical work of

this thesis (Experiment 1).

First field duration (Sd1), ISI and following field duration (Sd2) were all independently varied in a fully factorial design. It was thought that because the full montage stimuli were lexical, either positive stimulus duration effects or alternatively, no effect of stimulus duration at all, might be found. The rationale for this prediction was that it was thought possible that information persistence might operate on lexical but not on pattern-only stimuli. If this was so then performance in the integration task might show similarities to partial report performance. An attempt was made to encourage this result by using four letter word collages and word-like stimuli in each successive field.

The general results did not support this argument: performance was found to be inversely related to all three duration variables where field durations ranged from approximately 16.67 ms to 100 ms and ISI ranged between approximately 16.67 to 50 ms. The only interaction was a marginally significant one between Sd2 and ISI.

Di Lollo's assertion that visible persistence processes have a constant duration measured from stimulus onset was not well supported. According to this idea, perceptual integration would be inversely related to SOA but the mix of Sd1 and ISI should be irrelevant to performance. Instead, each duration function appeared to be different: ISI exerted the strongest influence, Sd2 was slightly weaker and Sd1, though still negative, exerted the weakest influence of all. However, interpretation in terms of absolute duration effects was limited because

stimulus energy and duration were confounded (stimulus intensity was constant).

The discussion arising from Expt. 1 concluded that the inverse Sd2 effect did not tie in with conventional ideas about visual persistence. There seemed to be no obvious reason why Sd2 should be important to integration; it has been generally assumed that as long as visible persistence from the first field is still available at the time that the following stimulus is registered (at the relevant processing site) then integration will occur. One possible answer was that a long Sd2 was capable of disrupting or terminating the processing of the first field (erasure masking).

To investigate this, Experiment 2 employed a backward masking paradigm with two types of mask. One mask shared the same contours as the target but nevertheless provided less information than the target (superposition mask). It was reasoned that if the Sd2 effects in Expt. 1 were due to the termination of first field (S1) processing then masking would be inversely related to mask duration. A second (bar) mask condition, where mask contours spatially overlapped the target and were incompatible with target contours, was included as a control. It was thought that this latter mask condition would be highly likely to impair performance and thus it would be possible to obtain an index of target maskability.

The results indicated that targets could be masked by bar stimuli but that the superposition mask was either ineffective or masking to a much lesser extent. More importantly, there was no significant effect of mask dura-

tion in either masking condition. It was concluded that the inverse Sd2 effect, found in Expt. 1, may be exclusive to successive field paradigms where stimuli do not spatially overlap. This seemed to imply that the idea that S1 processing could be terminated by a long duration following field (S2) was unlikely to provide an adequate explanation for the influence of Sd2 on integration.

In Experiment 3, the interest was to investigate whether the inverse Sd2 effect could be generalized to pattern only collages. The missing dot task was used for this. The independent variable was Sd2. This ranged between 10 and 200 ms, and intensity was adjusted so that all stimuli appeared to be approximately equal in brightness.

The results showed a strong monotonic deterioration in performance with increases in Sd2. There was some evidence that poor performance was related to loss of visual information about the leading stimulus field. This was concluded because well over 50 % of errors were selected from 1st field locations when Sd2 was 50 ms or greater. This proportion tended to increase with increasing Sd2 but the relationship was not quite significant (see also Expt. 6).

This experiment confirmed the robustness of the inverse Sd2 effect. One hypothesis that seemed promising was the idea that two successive fields did not become perceptually integrated (i.e. they remain perceptually segregated) until the termination of the following stimulus field. This would explain the Sd2 effect because persistence from S1 would be decaying over the whole time

that the following field was physically present, as well as over the ISI period, before it could become perceptually integrated with S2.

The above hypothesis implies that information about successive fields is processed separately until the following field's physical termination. After this point in time, however, both fields are processed together. If this is so then onset and offset detection responses might be necessary to facilitate these operations. Onset detection might be important to the allocation of separate feature processing channels. Offset detection might be important as a means of triggering the separate processing channels into amalgamating their respective information loads. It was pointed out how Di Lollo (1980) and Di Lollo and Bourassa (1983) may have demonstrated the importance of onset detection (their explanation for their findings was different in some aspects and did not anticipate the possible importance of an offset detection response).

The aim of Experiment 4 was therefore to determine if the hypothesized integration response was triggered by the detection of S2 offset. Missing dot tasks were used where one set of conditions was expected to induce offset detection within S2 prior to its physical termination. This was done by briefly intensifying the leading part of the S2 stimulus (E.set). It was thought that the intensity drop at the interface between the leading intensified edge and the following trailing portion of S2 would generate an early offset signal.

The general hypothesis seemed to be confirmed for

two reasons: (1) Performance in this condition was always superior to a control condition where a similar Sd2 (150 ms) without intensification was used; and (2) there was no significant effect of the brightness of nonintensified stimuli (Control 1). The latter observation showed that the overall brightness of S2 was not of great importance when Sd2 was long. This, in turn, implied that the intensity drop at the interface within S2 was responsible for facilitation rather than the overall increase in brightness which accompanied intensification.

A secondary finding that helped confirm the offset detection idea was that performance was inversely related to the duration of the intensified portion of S2. It was thought that this might happen because the latency for detecting the intensity drop should be inversely related to intensification duration.

In a second control condition (Control 2), where nonintensified S2 fields were presented at Sd2s which could be directly compared with intensification durations, there was no apparent Sd2 effect. Moreover, performance in this control condition was always superior to intensified conditions. It was argued that the deficit in intensified conditions could have been due to the strong contrast between S1 and S2 stimuli (contrast was absent in nonintensified variable Sd2 conditions).

On the other hand, it was expected that the influence of intensification duration and the variable Sd2 would be the same because of their supposedly similar offset latencies. The fact that the performance slopes of E.set and Control 2 were different was tentatively put

down to a minor artefact in E.set stimuli.

It was suggested that the Sd2s in Control 2 conditions may have been too short to replicate the inverse Sd2 effect (where the maximum Sd2 was 50 ms). When these conditions were compared with Control 1 conditions the effect was quite obvious.

The aim of Experiment 5 was to provide a more rigorous evaluation of the influence of the three basic temporal components (i.e. Sd1, ISI & Sd2) on integration. The missing dot task was used again and the design of this experiment was such that Di Lollo's assertion, that integration performance would be unaffected by the mix of Sd1 and ISI as long as SOA was held constant, could be investigated. A similar assertion about the higher order relationship between SOFFA and integration was also followed up. All stimuli were brightness equated so that direct conclusions about duration effects could be obtained. Total display durations of 75 and 95 ms were used.

It was demonstrated that integration was inversely related to all three basic duration variables but that SOA and SOFFA did not determine performance *per se*. In other words, the functions of Sd1, ISI and Sd2 were all different so that the mixes of Sd1 and ISI (within a constant SOA) and ISI and Sd2 (within a constant SOFFA) were important. The findings of Expt. 1 were replicated in that the strongest influence on integration was found to be ISI, while the weakest was Sd1.

The results of this experiment presented a problem for Di Lollo's idea that persistence processes are generated at stimulus onset. If this were true then, as men-

tioned earlier, the mix of Sd1 and ISI would not be important. Similarly with the idea that integration is not usually triggered until the termination of S2, only total duration should have been important (the mix of all three temporal components would have been irrelevant).

It was therefore suggested that temporal integration performance might also be limited by a second process as well as by persistence decay. The different functions of the component display duration parameters might then be evidence of interactions between these two processes. It was thought that the second process might be linked to perceptual segregation but it was unclear how it might function to inhibit perceptual integration.

One possible ramification to this was that the inverse Sd1 effect might be due to the second process instead of to the decline in availability of persisting visual information. In this case, the inverse Sd1 effect might not be evidence that persistence duration was inversely related to stimulus duration. This was thought to be a useful idea in that persistence might, after all, begin to decay at stimulus offset. This, in turn, might obviate the need to postulate that visible and information persistences are qualitatively different; there might be other ways of dealing with the problem of why partial report results do not agree with temporal integration results.

Experiment 6 was designed to demonstrate the operation of perceptual segregation. The usual 5x5 dot matrix, presented in two successive fields, was used with the exception that the dots in the first field formed the

shape of a single letter (10 different letters could be used). Thus, if the first and second fields had been seen in continual superimposition, the identity of the letter would have been perfectly masked.

Only Sd2 was independently varied (between 1 and 100 ms), Sd1 and ISI remained constant at 1 and 40 ms respectively. Both stimulus fields were equated in apparent brightness.

Two experimental tasks were incorporated into the design. The first task was the usual locating of the missing dot. This was needed in order to obtain an index of temporal integration. It was expected that Expt. 3 would be replicated here. The second task was to report the identity of the letter in the first field. This task therefore provided an index for letter masking. A third (control) task was incorporated to ensure that any reduction in masking was not due to the artefact of paired associate learning of S1 letters and their complementary S2 designs.

Clearly, in conditions where temporal integration was relatively good (i.e. when Sd2 was short), masking was expected to be strong because good perceptual amalgamation of S1 and S2 would obscure letter identities. However, at least two possibilities existed for the way that masking would vary with increasing Sd2: (1) If S1 and S2 remained perceptually segregated until the offset of S2 then the letter would have more time to be processed in isolation at the longer Sd2s. The degree of masking would therefore be inversely related to Sd2; or alternatively (2) if there was no perceptual segregation then Sd2 would

make little difference to masking because the time available to process S1 in isolation would only be dependent on Sd1 plus ISI.

The results indicated that both integration and masking were inversely related to Sd2. The former function was monotonic but it was thought that certain practice effects prevented the masking function from becoming entirely monotonic. Masking varied from just under 50 % when Sd2 was 1 ms (integration performance was over 90 % successful here) to around 10 % when Sd2 was 100 ms (integration was around 40 %). The control condition indicated that paired associate learning was not responsible for the masking results and the idea that successive fields remain perceptually segregated until the final termination of a successive field display was therefore upheld.

The probability of selecting missing dot errors from 1st field locations significantly increased with increasing Sd2. This result was interpreted as evidence that persistence from S1 was indeed decaying (see also Expt. 3) but since missing dot performance was still above chance when Sd2 was 100 ms, it was thought that persistence must still have been available 140 ms after S1 offset. Moreover, this was supported by the fact that masking was not minimized until Sd2 was 100 ms.

It was also found that integration performance was significantly influenced by the identity of the letter in the S1 field but this was only true when Sd2 was 50 or 100 ms. It appeared that the more compatible the shape of a letter was with the aspect of a fully integrated square

matrix then the greater the probability of successful integration performance. The tentative explanation for this was that the greater the degree of S1 processing, at a feature analysis level, then the less the propensity for S1 and S2 to become perceptually integrated at S2 offset. Thus, when elements comprising the letter stimulus reached a relatively high degree of perceptual organization, perception may have become fixed so that the S1 elements could not link easily with S2 elements. When letter shapes were incompatible with the orderly row and column format of the full collage, perceptual linkages between S1 and S2 may have been hindered to a greater extent than when letter shapes were compatible. Perceptual organization might be expected to improve from the early moments of stimulus reception. Thus, with a short Sd2, integration might have been triggered before S1 processing had proceeded very far. This might explain why the S1 shape did not influence performance when integration was good.

It was felt that this might be the second process that had been thought to limit integration (see discussion on Expt. 5). If this were so then the inverse Sd1 effect need not be evidence of persistence processes generated at stimulus onset. Instead increasing Sd1 would reduce the propensity of S1 to integrate with S2 at its termination due to the higher degree of perceptual organization of S1. This process would continue during the ISI and Sd2 period. Persisting information about S1 would not begin to be lost until its physical offset and this would also show its influence by reducing integration

performance as ISI and Sd2 increased. This would also explain why the Sd1 and ISI functions were found to be different; there would be no reason to suppose that the rate of changing perceptual organization would match the rate of persistence decay.

The aim of Experiment 7 was to investigate a possible loophole in the conclusions arising from letter masking in Expt. 6. It was reasoned that if persistence from S1 was decaying prior to, and during, S2 presentation then, even though S1 and S2 had been brightness matched, S1 might have sometimes appeared to be dimmer than S2. If subjects could take advantage of the resulting inverse contrast then letter masking may have been reduced. Furthermore, masking could conceivably have become inversely related to Sd2 because persistence would have had longer to decay as this variable increased. In this case, the inverse masking effect would not have been evidence of perceptual segregation.

To investigate this, some letter masking conditions from Expt. 6 were repeated. This time, however, S2 intensity was also adjusted so that it could appear to be much dimmer or much brighter than S1. If observers could take advantage of inverse contrast then masking would decline when S2 was brighter than S1. Two observers who had undertaken Expt. 6 took part here so that their performance in the two experiments could be compared.

It was found that one observer's performance deteriorated in the bright S2 conditions while the other observer remained unaffected by brightness. Since both observers had demonstrated inverse masking functions in

Expt. 6 (this was replicated, for each brightness condition, in the present experiment) it was concluded that apparent inverse contrast was not responsible for their masking functions. Hence, there was no reason to doubt the conclusions from Expt. 6.

Expt. 7 also included the missing dot task in order to further investigate the effect of S2 brightness on integration. It was noted that brightness did not greatly affect performance when Sd2 was long (100 ms) but other results were fairly inconclusive.

The results so far had indicated that temporal integration performance could be explained by a dissociation hypothesis that incorporated three basic ideas:

(1) There is a global loss of visual information. This loss probably begins after stimulus offset although this was not entirely certain.

(2) Successive fields remain perceptually segregated until following field offset. Thus, the availability of persisting visual information is important to perceptual integration only after the whole display has terminated.

(3) There is a tendency for information about successive fields to remain perceptually dissociated even when the integration process has been attempted after display offset. The degree of perceptual dissociation is inversely related to the level of perceptual organization in the first (and possibly the following) field. The level of perceptual organization increases as a function of the time period that the field has been processed in isolation (i.e. while it is perceptually segregated). Thus, the longer the total display duration, the greater

the degree to which successive fields will remain perceptually dissociated after the full display has terminated.

There are therefore two processes which limit integration performance. The first is global persistence decay and the second is the tendency towards perceptual dissociation.

Experiment 8 was an attempt to generalize the findings about temporal integration to the partial report paradigm. This was considered to be possible because the dissociation hypothesis appeared able to explain integration performance without recourse to the idea that visual information is lost from stimulus offset and hence it might be wrong to suppose that the inverse Sd1 effect implies that persistence duration is inversely related to stimulus duration. It was therefore thought that the hypothetical dichotomy of visible and information persistence might also be spurious.

This experiment used a 5 x 2 stimulus array with a spatially nonoverlapping narrow bar probe to cue targets. Array duration (Sd1), probe delay (ISI) and probe duration (Sd2) were independently varied. Two methods of report, single letter (SL) and full row (FR), were used.

The dissociation model predicted that performance would be inversely related to all three temporal variables with the SL report mode but that the FR mode would only demonstrate inverse functions for ISI and Sd2.

The basis of these predictions was developed from the three previously discussed ideas contained in the above model. As before, two processes were expected to influence performance: (1) Visually literal persistence

decays from array offset. Target selection would not begin until probe offset so that persistence decay would cause performance to deteriorate with increases in probe delay and probe duration; and (2) the propensity for the array and probe fields to become perceptually integrated at probe offset would decline with increasing array duration, probe delay and probe duration. It would be expected that the resultant inter-field dissociation would induce perceptual misalignments between the array and the probe so that misalignments would increase as all three temporal parameters increased.

Array-probe misalignments would have affected overall performance less in FR conditions than in SL conditions. It was for this reason that array duration was not expected to show an influence with FR performance. Ironically, it was only in FR conditions that misalignment errors might be distinguished from other kinds of transpositions (residual errors).

The predictions of the above hypothesis were contrasted with two versions of the perceptual drift hypothesis which state that spatial information about arrays is lost more quickly than identity information. Drift hypotheses explain performance deficits mainly in terms of errors being caused by the decline in availability of the former type of information. They conclude this from the fact that most PR errors are transpositions.

One version proposes that spatial information begins to be lost after stimulus onset and therefore predicts that an inverse relationship would be found with Sd1 and ISI. The other version states that persisting spatial in-

formation is lost after stimulus offset so that performance would only decline with increasing ISI (the visible-information persistence dichotomy was implicit within this version). Neither version takes probe duration into consideration.

The dissociation hypothesis was virtually entirely supported by the results. Further analyses of transposition errors supported the idea that some of them were indeed caused by array-probe misalignments. It was found that this tendency was positively related to all of the temporal variables and this supported the idea that misalignments were due to perceptual dissociation between the array and the probe.

Since the apparent differences between temporal integration and partial report performance could be accounted for by a single model of dissociation, it was concluded that the basis for postulating a visible and informational persistence dichotomy is spurious.

5.2 Summary of conclusions

This section summarises the main conclusions arising from the research

. In order to present a complete picture it is necessary to include a certain amount of speculation.

1. The probability of the temporal integration of two visual fields with nonoverlapping contours is inversely related to:

a) First stimulus field duration (Sd1).

b) Inter-stimulus-interval (ISI).

c) Second stimulus field duration (Sd2).

Each of these functions is different: ISI exerted the strongest influence while Sd1 exhibited the weakest influence. The only evidence of interaction was a marginally significant ISI x Sd2 effect (Expt. 1).

These relationships were insensitive to the type of information that was displayed in the collage.

Where the probability of integration was less than approximately 80 % (observed when Sd2 was equal to, or greater than, 30 ms) then more than 50 % of errors were due to loss of information about the leading field. This tended to increase as integration declined.

2. The process of perceptual integration does not normally begin until the termination of the following stimulus field. This process is triggered by detecting the sudden fall in intensity that accompanies offset.

3. Integration is influenced by the shape of the leading stimulus (it was thought possible that the shape of the following field might also exert an influence). This effect was not found to occur when the probability of successful integration was above 80 % (i.e. when Sd2 was less than 50 ms in Expt. 6).

It was noted that the less compatible the shape of the leading stimulus and the aspect of the entire collage then the less was the probability of integration.

4. Backward masking with nonoverlapping contours (where targets are camouflaged by masks) is inversely related to mask duration.

Where target and mask contours do overlap then backward masking is either unrelated to mask duration or a slightly positive relationship is found.

5. The general conclusions about temporal integration of fields with nonoverlapping contours were:

Visual information about successive fields remains perceptually segregated until the offset of the following field. Upon the termination of the following field, a period of perceptual integration is initiated. The probability that integration will be successful is limited by two processes:

a) The decay of a literal form of visual persistence; this process commences at stimulus offset and continues to influence performance at least until the offset of a following field.

b) The degree to which visual information about the leading field (and possibly the following field) becomes perceptually organized; the greater the degree of organization at the termination of the following field then the greater the degree of inter-field dissociation and, therefore, the less the propensity for integration. Perceptual organisation, and hence perceptual dissociation, increases with increasing processing time.

6. Partial report, with the use of spatially non-overlapping visual cues, is partly mediated by similar processes to those involved in temporal integration. There is no qualitative difference between visual persistence in temporal integration and visual persistence in partial report.

The degree of perceptual dissociation (between array and probe) after probe offset positively influences the probability of array-probe misalignments. This causes partial report results to be dependent on the report method used:

a) *SL report*: Probe-array misalignments lead to increasing transposition errors with increasing array duration, probe delay and probe duration. Persistence decay begins at stimulus offset and accounts for increasing errors with increasing probe delay and probe duration. The resulting performance is inversely related to all three duration parameters.

b) *FR report*: Persistence decay has the same effect as with single letter report. However, increasing the temporal parameters in this report mode accounts for only small increases in the number of transpositions which are attributable to probe-array misalignments. Performance here is inversely related only to probe delay and probe duration.

Not all transpositions in partial report are accounted for by probe-array misalignments. Another class of transpositions (residual errors) was also seen to operate and these normally obscure the evidence for misalignment. There was little evidence that these errors are consistently influenced by any duration parameters.

5.3 Discussion

Most direct ways of investigating persistence make use of successive visual presentations and it is possible that the present findings could apply to them. As pointed out in Chapter 1, the *visibility* of the persistence implied by many of these research techniques is questionable.

More specifically, the conclusions reached in this thesis have directly implied that the *visibility* of visual persistence may not be a particularly useful concept when considering tasks associated with temporal integration and partial report procedures. This must be so if successively presented stimuli remain perceptually isolated for a time. It seemed, with these tasks, that

the useful percept was that which occurred after display offset. Whether or not there were visual sensations over the whole period between the time that a stimulus was first registered and the time that a response was selected seemed to be largely irrelevant to performance, not to mention unquantifiable.

It may be that the use of the term *visible persistence*, when applied to some direct methods of investigation, is simply unfortunate, its main purpose having been to differentiate this type of persistence from that implied by partial report. However, it has been demonstrated that this distinction may, in itself, be a spurious one since there appear to be other ways of accounting for the differences between direct and indirect techniques.

Inverse stimulus duration effects have been found with the use of cross modal stimuli. For example, where Efron (1970b) used an auditory probe to measure visual persistence with the *judgement of synchrony* technique (see Chapter 1). However, little attention was paid to the duration of the probe and it may be that there are certain similarities between cross modal integration and purely visual integration.

It also would be interesting to know whether partial report could be sensitive to the duration of an auditory probe. This might be expected if subjects suspend their selection decisions until tone offset in the same way as they apparently did with visual cues (see Expt. 8).

A model of perceptual dissociation in successive fields

The dissociation hypothesis appears to explain how temporal integration and backward masking, where mask contours do not overlap with target contours, can be inversely related to following field duration but it would be thought that the same might also apply to backward masking with overlapping contours; there is no obvious reason why target and mask should not appear to dissociate in the latter situation. However, this has been contraindicated by Expt. 2, where mask duration had no effect, as well as by other similar kinds of investigation (see Ch. 4 in Breitmeyer 1984).

This problem might possibly be resolved, however, if a single sensory store (such as the kind envisaged by Sperling, 1960) could be accessed by at least two processing sub-channels (Channels 1 & 2). The latter's purpose is to organise the literal information, held in storage, in order to construct a usable percept. The sensory store might be continually fed by retinal activity but would maintain the input for some time after the physical stimulus had terminated. The amount of time that visual data persists, at each point in the store, would be constant from the moment of stimulus termination. Because there is only a single sensory store, it is possible that the visual data contained in it might be disrupted at points where the contours of successive fields overlap.

Each sub-channel would receive input from the store on a point to point basis. Channel 1 would operate on all material generated by the leading stimulus but would be

effectively blind to stored information generated by the following stimulus and *vice versa* for channel 2. It seems possible that an onset signal generated by the following stimulus could be the trigger that stimulates channel separation. As discussed in Chapters 1 and 2, Di Lollo (1980) and Di Lollo and Bourassa (1983) may have demonstrated the importance of onset detection to temporal integration performance.

After the following field has terminated, the sub-channels combine their operations to effectively become a *super-channel*. If neither sub-channel had fully completed their operations then the super-channel would continue their work but would not be concerned whether its information had originated from Channel 1 or Channel 2. It would, however, have to undertake the job of linking the unfinished constructs from Channels 1 and 2 together. Linkages between inter-channel elements might be expected to be weaker than linkages between intra-channel elements because the latter would have had more time to be processed. Perceptual integration might depend on the strengths of inter-channel links; the weaker these were, relative to intra-channel links, then the poorer would be the integration.

It is quite possible that identification processes (such as character identification) work in parallel to perceptual organisation (Lupker, 1979). If this is so then intra-channel identification could occur prior to the time that either sub-channel had fully completed its work.

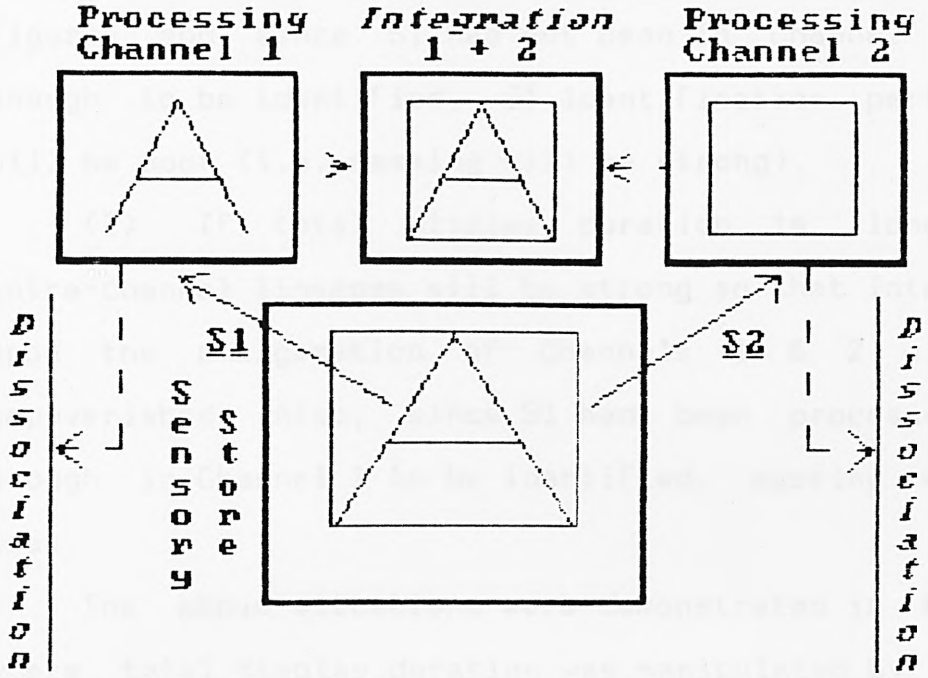


Figure 5.1: Operation of the dissociation model with non-overlapping successive field contours. See text for details.

Figure 5.1 depicts the model in respect of successively presented fields which do not have overlapping contours. The first stimulus to be presented is the letter *A* (S1). Retinal information about this stimulus is transferred to the sensory store, which in turn feeds processing Channel 1 where perceptual organization takes place. The following stimulus (S2; *inner rectangle*) is placed into the sensory store in retinotopic relationship to S1. Visual data, solely about S2, go straight to Channel 2. During the S2 presentation period, stimulus organization processes are continuing in separate channels. There are two possible scenarios here:

(1) If total display duration is short then the intra-channel linkages will be weak so that S1 and S2 can be easily amalgamated. Performance in an integration task will be good. In terms of masking, S1 will be camouflaged

by S2 (some imagination is required to see this from the figure) and since S1 had not been in Channel 1 long enough to be identified, S1 identification performance will be poor (i.e. masking will be strong).

(2) If total display duration is long then intra-channel linkages will be strong so that integration upon the amalgamation of Channels 1 & 2 will be impoverished. Also, since S1 had been processed long enough in Channel 1 to be identified, masking will be weak.

The above situations were demonstrated in Expt. 6 where total display duration was manipulated by varying S2 duration.

The outcome would be different if successive field contours overlapped. This condition is depicted in Figure 5.2. S1 (*A*) and S2 (*shaded inner rectangle*) are again placed in retinotopic relationship into the sensory store. Information about S1 is fed into Channel 1 but the flow of information will be partially disrupted because the advent of the mask would interfere with S1 data in the sensory store. Thus, if SOA is short, perceptual organization in Channel 1 may remain impoverished. Integration between S1 and S2 may still proceed successfully, depending on whether S2 duration is short or long, but S1 identification performance will remain poor regardless of S2 duration.

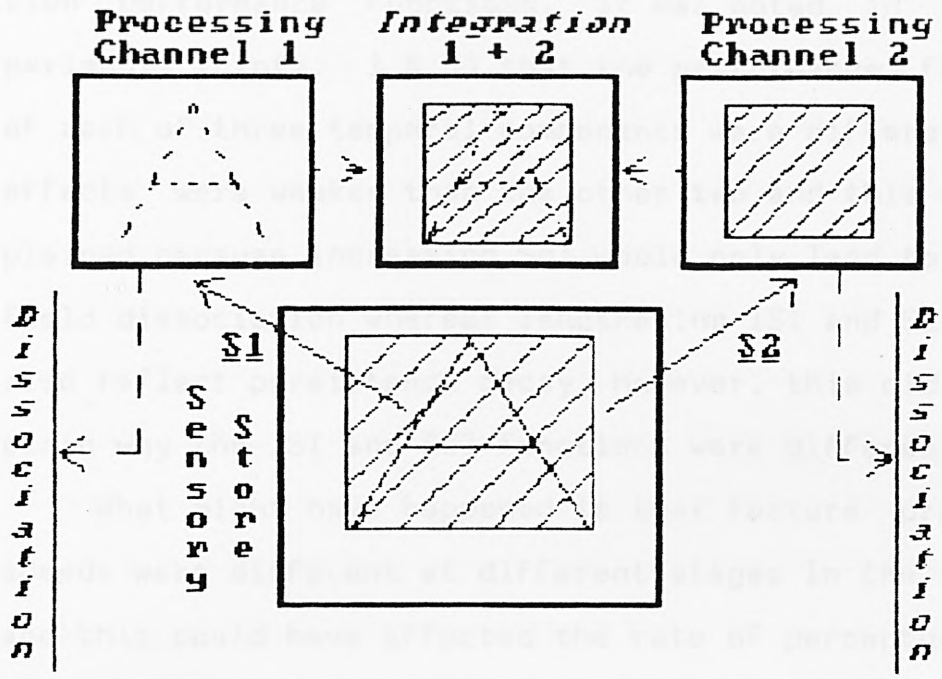


Figure 5.2: Operation of the dissociation model with overlapping successive field contours. See text for details.

It seems probable that normal everyday vision makes use of the full capacity of the super-channel. Eye fixations normally last well over 200 ms and this amount of time may usually be long enough for feature processing to run its course. It may therefore be that the super-channel can discharge itself when its work is done, perhaps during saccades, to await visual input from the next fixation. However, where rapid changes in the visual field occur (for example, in the perception of moving objects) then the super-channel subdivides itself as discussed above.

Since sub-channels are fractionations of the super-channel, it may be that the processing power of each of these is limited accordingly. This implies that processing speeds may be variable with multi-field displays and this idea might bear on certain differences in integra-

tion performance functions. It was noted in two experiments (Expts. 1 & 5) that the performance functions of each of three temporal components were different. Sd1 effects were weaker than the other two and this was explained because increasing Sd1 would only lead to greater field dissociation whereas lengthening ISI and Sd2 would also reflect persistence decay. However, this did not explain why the ISI and Sd2 functions were different.

What might have happened is that feature processing speeds were different at different stages in the display and this could have affected the rate of perceptual dissociation. Changes in the rate of dissociation may have affected integration performance thus:

(1) Processing speeds during the Sd1 period would be fast because the super-channel has yet to be divided into sub-channels. Increasing Sd1 would have a relatively powerful influence on dissociation. This, in turn, forms the basis of the inverse Sd1 effect.

(2) Over the ISI period, dissociation increases at the same rate as during the Sd1 period but now persistence is also decaying. The sum effect of both these processes leads to a much stronger negative acceleration in performance with increasing ISI.

(3) During the Sd2 period, sub-channels split off from the super-channel and feature processing rates therefore slow down. This, in turn, slows down the dissociation rate. Persistence decay is still operating but the slowed dissociation means that although the negative performance function due to Sd2 will be stronger than that due to Sd1, it will be weaker than the inverse ISI

effect.

The idea that changes in visual processing loads can alter feature processing speeds is not a new one. Kahneman and Treisman (1984) have discussed how the naming latency of a word can be increased when another word or simply a block of dots is presented, at the same time, to a different spatial location. In another series of experiments, where a variation of the Stroop effect was employed, subjects were required to name the colour of a briefly presented bar. As might be expected, when a conflicting colour word was included in the display then response latency increased. However, response latency was also increased (by different extents) by neutral words and even by a simple row of *x*s. Coltheart (1984) has offered the following interpretation in respect of these experiments and others like them:

> "When there are several objects, of whatever category, in the visual field, a target object is dealt with less efficiently by some early perceptual or attentional stage...but this is not because of the limited capacity of some post-categorical stage: It is because of limitation of simultaneous processing at some precategorical stage (since the limitations occur even when the interfering items do not enter the postcategorical stage)".

As discussed in previous chapters, many of Di Lollo's findings can be explained by the present thesis. Some of his results can be seen to represent a special case for the dissociation hypothesis. For example, Di Lollo (1980) ingeniously demonstrated that, where target and noise mask stimuli terminated at the same time then the degree of masking was inversely related to mask duration. His explanation for this was that persistence dura-

tion was inversely related to stimulus duration. Thus, even though target and mask terminated at the same time, persistence about the shorter duration target would outlast that of the longer duration mask.

According to the dissociation model, target and mask would be processed in segregation if onset asynchrony were long enough to allow the super-channel to become fractionated into sub-channels. This explains Di Lollo's results because provided the SOA was sufficient to enable isolated processing and at least one stimulus duration was long enough to give strong dissociation, then the target might be expected to appear to *stand out* from the perceptual noise of the mask.

In relation to this, it is interesting to note that Wilson (1983), used dot bigram targets that were spatially and temporally embedded in nonoverlapping dot masks. In one experiment, mask duration was 1280 ms and a 40 ms target was presented so that stimulus offset asynchrony (SOFFA) ranged from 0 to 120 ms. Wilson demonstrated that masking was inversely related to SOFFA. Di Lollo would have difficulty in explaining this result because he would expect that the length of time by which target persistence outlasted the mask would be greatest when SOFFA was 0 ms. Thus, since target perceptibility would be expected to increase as the period of perceptual overlap between target and mask decreased, masking should be positively related to SOFFA. In contrast, the dissociation model would predict the result that was found. A long SOFFA, as opposed to a short one, would give more time for the target to be processed in perceptual segre-

gation and this would increase the probability of target identification.

Onset and offset detection responses.

Onset and offset detection responses were implicated in the present research and it is tempting to relate these to the operations of transient neural networks. Singer and Phillips (1974) demonstrated that certain cells in a cat's lateral geniculate nucleus (LGN) (the site of the first post-retinal neural relay centre) were able to respond briefly, after a short delay, to the onset of a light in the centre of their receptive fields. These were called ON-centre cells. Other cells in the LGN (termed OFF-centre cells) responded exclusively to the offset of the light. They were able to demonstrate that mutual inhibition occurred between ON- and OFF-centre cells.

The OFF- response is small or nonexistent with very brief light flashes because that response is inhibited by ongoing ON-centre cell activity. No such inhibition of OFF-centre activity would occur with long duration flashes since ON-centre activity, which was found to endure for no more than 60 ms, would be over by the time the transient OFF- response was triggered. Likewise, ON-centre activity can be inhibited by OFF-centre activity: If a light flash was briefly interrupted then the ON- response that followed the interruption was muted or disappeared entirely. The strength of this inhibition declined as ISI increased. Other inhibitory combinations were also considered.

The importance of this work became clear when Phillips and Singer (1974) were able to apply these neurophysiological findings to psychophysical studies. In these studies (see also Royer and Gilmore, 1985; Stelmach *et al*, 1984), it was demonstrated that the detection of appearances and disappearances of single elements between otherwise identical successively presented multi-element displays could be predicted from a knowledge of ON-OFF-centre interactions.

Although a response to the detection of offset was implicated in this thesis (Expt. 4), the possibility that this *was* mediated by the transient OFF- responses described by Phillips and Singer seems unlikely. If this were the case then it would be necessary to postulate that integration performance was inhibited (rather than triggered) by the detection of an offset signal in the following field. This would be indicated because the magnitude of the transient OFF- response would not be maximised until Sd2 had increased to approximately 60 ms.

On the face of it, this explanation would also predict an inverse relationship between performance and Sd2 and there would be no need to postulate the notion of perceptual segregation. However, there are two reasons for believing that the problem of the inverse Sd2 effect cannot be resolved in this way. Firstly, Expt. 4 demonstrated that a sudden drop in S2 luminance (caused by intensification of the leading part of S2), only 10 ms after stimulus onset, could greatly improve integration. However, a transient OFF- response would probably have become inhibited by the ON- response (to S2 onset) that

arrived 10 ms earlier. Hence, the only transient OFF- response to intensified S2 stimuli should have occurred in response to the final termination of the display which was 150 ms after S2 onset. Thus, if integration were inhibited by transient OFF- responses, performance in this condition should have been no better than in conditions where S2 intensity was constant over the full length of its presentation period; the only transient OFF- response to S2 in both conditions would have been when S2 finally terminated 150 ms after its onset. However, as was clearly demonstrated in that experiment, performance in the leading intensification condition was superior to that where there was no intensification, as long as overall Sd2 remained constant throughout both conditions.

Secondly, if temporal integration performance were inhibited by the generation of transient OFF- responses there would be two ways that a successful subject response could be promoted: (1) As mentioned above, Sd2 could be very short; or (2) it could be very long. The latter condition ought to allow for perceptual integration to be completed prior to the termination of S2. Thus, if the lack of S2 OFF-centre activity was necessary for successful integration then Sd2 effects should demonstrate a *U* shaped function. The trough of this function would occur when Sd2 was approximately 60 ms (i.e: where the magnitude of OFF- centre activity was maximized). Performance might be expected to improve after this point as the perceptual overlap between stimulus fields increased. These predictions were not supported by the data: A monotonic decline in integration performance was

always demonstrated by increasing Sd2. This was so even when Sd2 was extended to 200 ms.

The possibility remains that not all ON- OFF-centre transient activity is mutually suppressive. However, the alternative might be that off detection responses are generated by some other mechanism. It may be that small changes in sustained cell activity would be sufficient for this purpose. This would be the kind of reaction that was described as Type I persistence by Hawkins and Schulman.

Persistence in the real world

Haber (1983) has argued that the concept of a persistence that is visible would be a redundant mechanism under normal viewing conditions. Typical eye fixations, where relatively stable retinal images are maintained, usually last for at least several hundred ms and all the information necessary to evolve a perception can be obtained from this source. He does not argue that visual persistence may not be an empirical reality but simply that it is not a useful concept "...as part of information processing". These ideas echo Neisser (1976):

> "The icon simply simulates, for the rest of the nervous system, the information that would be picked up if the real display were still on. Nevertheless, it can play little part in normal vision: by definition it does not exist while a given fixation continues, and it is destroyed by masking after every eye movement. Although the exact retinal arrangement of still unperceived forms may be briefly stored under tachistoscopic conditions, this storage is not persistent or robust enough to affect the perceptual cycle"

The arguments presented in this thesis are strongly opposed to this viewpoint. Some form of sensory storage

that maintains visuo-spatial information has been demonstrated here. It was thought that this store is a low level but essential component of feature analysis whereby raw visual data becomes perceptually organised into usable information about the world. This idea bears some resemblance to the *global-to-local* model of letter perception that was investigated by Lupker (1979). He suggested that:

> "...letter perception might be better viewed as a focusing process wherein the observer's initial 'view' of the letter is a blur of perceptual data. Over time, the excess figural information is gradually lost until, after relatively extensive processing, the letter's local aspects finally become available".

With this view the need for persisting visual information makes more sense. The eye is only the source of raw visual data but for an image to be clearly perceived, this data must be cleaned up and transformed. In order for this to be possible some way of storing the original visual information output might be necessary.

According to both Haber and Neisser, visual persistence would be a hindrance to normal every day perception. However, in contrast, the dissociation model implies that persistence could, in some circumstances, improve perceptual processing power. In situations where the contents of a sensory store were not heavily disrupted by an

aftercoming stimulus then perceptual processing of the original stimulus could perhaps continue. For example, data generated by one fixation might not entirely disrupt visual information, in the sensory store, that was generated by a previous fixation. Thus it might be that visual processing from one fixation could continue into the next. This might result in more efficient visual processing between successive eye fixations because information could be processed for a longer time. There would be no problem of persistence from the first fixation directly interfering with the following one because, under normal circumstances, eye fixations endure long enough to promote perceptual dissociation.

The ideas incorporated into the dissociation model might also be of value in the study of motion perception. Although certain "hardwired" neural circuits have been implicated in the registration of motion across small visual angles, Anstis (1980) hypothesized that for more complex stimuli, which move across a wider angle of view, a cognitive system of evaluating motion would be necessary. Persisting but perceptually isolated information, where each segregated image holds a slightly different scene as an object changes position, might, in some way, provide the means to evaluate aspects of motion.

5.4 Summary

All the work from previous chapters was reviewed and the main conclusions arising from this were summarized. Two of the most important of these were that: (1) Temporal integration involves multiple processes and is not solely dependent on persistence duration; and (2) there

may be no real grounds to propose the distinction that visual persistence implied by temporal integration techniques and visual persistence implied by partial report techniques are qualitatively different.

A skeletal dissociation model, where successively presented stimuli may sometimes be processed in separate channels, was discussed. Various problems were highlighted and one or two solutions to these were proposed. Also, the point was made that the offset detection responses that were implicated in much of the present research were unlikely to have been generated by the kind of transient responses investigated by Phillips and Singer (1974).

It was speculated that the form of visual persistence implied by the dissociation model might be necessary to normal everyday perception. Some mention was made of potential benefits of this type of processing mechanism.

APPENDIX 1: PILOT STUDIES

This appendix presents five pilot studies that were ancillary (but generally considered to be necessary) to the experiments reported in the main body of this thesis.

Pilot 1: Preparation of word pools (Expts. 1 & 2)

The aim of this investigation was to grade single stimulus subunits for letter identifiability. The data from this experiment were to be used to help decide the selection of stimuli for Expts. 1 and 2.

Subjects

Nine male and nine female 1st and 2nd year undergraduate psychology students were used. The age range was between 18 and 27 years. All had normal or corrected to normal vision. All spoke English as a first language.

Stimuli

654 four letter words (see Table A1.3) were chosen from the word list compiled by Kuçera (1967). These words were selected randomly except that a fair spread of first letters and word frequencies were chosen.

Each stimulus was either a single presentation of a subunit 1 or subunit 2 degradation of one of the words in the list. A full description of these stimuli has been provided in Expt. 1 (see also Figs. 2.1 a and b).

A.1

Method and Procedure

The task in this investigation was to report (and correctly locate) as many letters as possible in response to single subunit presentations.

All the apparatus, display intensity and laboratory conditions were identical to those described in Expts. 1 and 2. As in those experiments the subject viewing distance was 6 feet.

Subjects were randomly assigned into pairs with the constraint that each pair consisted of one male and one female subject. For 8 pairs of subjects, one member was presented with 70 subunit 1 stimuli and the other member was presented with a similar list except that they were in subunit 2 format. The procedure was similar with the ninth subject pair, except that each member was presented with 94 stimuli.

Trials proceeded as follows: The subject initiated each trial by means of a hand-held button. Immediately after this a central fixation stimulus (see Expts. 1 and 2) appeared for 500 ms. This was followed by a blank period for a further 500 ms and then by a subunit presentation for 200 ms. The subject then gave a verbal response and this was written down by E.

S's were provided with twenty practice trials prior to experimental trials (the practice stimuli words were not part of the experimental set). During practice, feedback was given but was withdrawn for experimental trials.

A.1

Results and Discussion

The ratings (i.e. number of letters identified in each subunit) for all 654 words are given in Table A1.3. Individual scores were converted to percentages of the total number of letters attempted by each S (see Table A1.1). As can be seen, letters presented in subunit 2 format appear to be more easily recognised than subunit 1. However a *t* test (two-tailed) on the data shows that these differences were not significant (t=-1.79, df=16, p=.093).

Given that the *t* test was not significant, it was of interest to determine whether the relationship between subunits and the number of letters recognised was likely to have been obtained by chance. A binomial distribution of expected to observed scores was calculated for both subunits (see Table A1.2), followed by two chi square goodness of fit analyses. Both subunit formats were shown to be highly significant (Subunit 1: X^2=204.9, Df=4, p<.001: Subunit 2: X^2=407.5, Df=4, p<.001).

It therefore seemed reasonable to conclude that some subunits promoted better performance than others. The reasons for this were not determined. It is possible that some degraded letters were more recognisable than others. It is also possible that letter recognition was influenced by whole subunit patterns. Also, some subunits may have given more clues about word identity than others.

Data Applications

The stimuli for Expt. 1 were selected from the 0 and 1 rated lists (see Appendix 2). Only those words where at

least one subunit had no letters recognized were included.

In Expt. 2, stimuli were selected from the same lists (Appendix 2). All words, except those used in Expt. 1, were eligible.

Subunit 1		Subunit 2	
Subject	% Score	Subject	% Score
1	25.36	10	48.93
2	14.64	11	41.07
3	12.50	12	17.86
4	32.50	13	25.71
5	33.93	14	34.29
6	22.14	15	18.21
7	26.79	16	35.71
8	35.71	17	40.71
9	30.85	18	50.27
Mean:	26.05	Mean:	34.75
Sd:	8.29	Sd:	10.34

Table A1.1 - Pilot 1: Total score per subject, expressed as a percentage of the total number of letters attempted. Each row represents one subject pair.

A.1

Subunit 1:

Words where:-	Number of words Observed	Expected
1 Letter recognised	218	275.47
2 Letters recognised	128	146.82
3 Letters recognised	36	34.79
4 Letters recognised	26	3.07
0 Letters recognised	246	193.78
Total	654	653.93

Total letters recognised = 686

Subunit 2:

Words where:-	Number of words Observed	Expected
1 Letter recognised	169	250.35
2 Letters recognised	161	204.44
3 Letters recognised	57	74.16
4 Letters recognised	65	10.07
0 Letters recognised	202	114.97
Total	654	653.99

Total letters recognised = 922

Table A1.2 - Pilot 1: Expected vs. observed frequencies of number of letters recognised.

A.1

0 Ratings:

LOVE USER HORN OVEN TUBA FUEL EDGE HALF HIVE BRAG CAGE
TERM ITCH DAMP DUEL ARAB LOAD BOND GAME DRUM QUAD TIME
ALTO BURN DYAD JADE ECHO ONYX DHOW YEAR OVUM AGED WORM
KITH LINK FORM TACK WADI NODE WOLF LIMP MYTH OATH ACID
DICE VOID SNOW SAKE CLAW HALO BROW FACE FEUD HARE DUNE
SODA OVAL ITEM MATE YARD ARCH KILO TUBE KIND DENT HARP
TAXI AEON BOWL BALD BAIL WHIP FLUX BEER SEAM CAVE WHIM
HACK RUIN ATOM HAIL CALM MAID HOPE TOUR

1 Ratings:

CAKE	1	1	VEIN	0	1	WINE	0	1	CLAY	0	1	PAWN	1	1	BEAK	1	1
BLOW	1	0	GULF	1	0	SHOP	0	1	AXLE	1	1	KNOB	1	0	COPY	1	1
BABY	1	0	SOCK	0	1	GRAM	1	0	FAIR	1	0	SNOB	0	1	HOUR	1	1
DEBT	1	1	WAIF	0	1	SWAB	1	1	PAGE	1	1	KNOT	1	0	QUAY	1	0
HIDE	1	1	WIFE	1	0	FOAM	1	1	SINE	1	1	EXIT	0	1	HOSE	0	1
LUTE	1	1	STUB	0	1	FRET	1	1	MEMO	0	1	ALMS	1	0	BUSH	0	1
HEMP	1	0	GOAL	0	1	CASH	0	1	ZINC	1	1	CHAP	1	0	PROW	1	0
HILT	0	1	HAIR	1	0	FLEA	1	0	PLUS	1	1	PEAR	1	0	BOMB	0	1
BASE	0	1	DRUG	1	1	PORE	1	0	DARE	0	1	CZAR	1	0	DEAL	0	1
STEW	0	1	YOGA	1	1	HERD	0	1	LIMB	0	1	BLUR	1	0	BEAR	1	0
HYMN	1	1	LEVY	1	1	NOVA	1	1	PILE	1	0	LAND	1	1	COVE	0	1
FOUR	1	1	MIEN	1	1	DUCK	0	1	FOAL	1	0	BEAD	0	1	GATE	0	1
STAR	0	1	CARP	1	1	GORE	0	1	SLOB	0	1	JUTE	1	0	TRAM	1	0
TRAY	1	1	TART	1	1	PLUM	1	0	FLEX	1	0	CHUM	1	0	EPIC	0	1
STUD	0	1	HAWK	1	0	DIKE	1	0	MEWS	1	1	LACK	1	1	HUNT	1	1
LADY	1	0	FIVE	1	0	LEAD	0	1	FLAG	0	1	GLOW	1	1	FILM	0	1
HELM	0	1	COAL	0	1	DOLT	1	0	BULB	0	1	CORK	1	1	MUCK	1	1
LAIR	0	1	ROAD	1	1	BLOC	0	1	WREN	1	1	PRAM	1	0	LURE	0	1
WART	1	0	PLAY	1	1	DIAL	0	1	LAMP	0	1	SPAR	1	1	BORE	1	0
WAGE	1	0	TALE	1	0	BUOY	1	1	FIFE	1	1	SPUR	0	1	DUCT	1	1
HOLE	1	0	LICE	1	0	BELT	0	1	FOLD	0	1	RUBY	1	1	JUDO	1	0
FROG	1	1	BOAT	1	1	COIN	1	1	SHOW	0	1	WASP	0	1	CHOP	1	0
ROTA	0	1	COMB	0	1	CLAP	0	1	RAND	1	1	MACE	1	0	TAPE	1	0
HIND	0	1	DOPE	1	0	REAM	1	0	PACE	1	0	IRON	0	1	MEAD	0	1
TIER	1	0	CROW	0	1	AGUE	1	0	TUNA	0	1	EMIR	1	0	GRUB	1	1
PALM	1	1	LYNX	0	1	CHAT	1	0	DYNE	1	1	PAIR	1	0	SHOT	0	1
SCAR	0	1	BENT	1	0	BODY	1	0	SWAN	0	1	FLAN	1	1	OPAL	1	0
BOOK	0	1	BACK	1	1	GEAR	1	1	HAND	0	1	CUBE	1	1	HOAX	1	1
SAND	1	1	BUST	1	0	WEIR	1	1	PLEA	1	0	RASH	0	1	FAWN	1	0
GERM	1	1	RATE	1	1	LUMP	1	1	ADZE	1	0	CORN	1	1	ZERO	1	1
TYPE	0	1	HEIR	1	0	ARMY	1	0	PEER	1	0	IDEA	1	0	VOTE	1	1

Table A1.3 - Pilot 1: Pool of 654 words from Kuçera (1967). The rating numbers at the top of each list indicate the maximum number of letters correctly identified in either subunit. Also, the actual score for each subunit is shown after each word (except for 0 ratings); the number pairs indicate the subunit 1 score followed by subunit 2. This table is continued on pages 301 and 302.

A.1

2 Ratings:

CORE	2	0	RAGE	2	0	FOLK	1	2	LACE	1	2	HASH	0	2	DIGS	0	2
DISC	0	2	RAIN	0	2	DARK	1	2	CLIP	0	2	BRIG	0	2	FLAW	2	0
PAIN	1	2	TOME	0	2	DOVE	1	2	LION	0	2	SOUP	1	2	POEM	2	0
BITE	0	2	FONT	1	2	FORD	1	2	CLUE	2	0	LORE	1	2	MEAL	2	1
LOCK	2	1	QUIP	2	0	SPOT	2	1	LANE	2	2	POLE	2	0	BUCK	0	2
NOSE	0	2	FORK	2	1	LIFE	1	2	ALLY	2	0	LUCK	2	1	RIOT	1	2
DATE	2	0	HERB	2	0	BLIP	1	2	COMA	2	0	PLOY	2	1	RUST	2	0
TICK	1	2	KING	0	2	REIN	1	2	LASH	1	2	FARM	2	0	MODE	2	0
ARIA	1	2	BLUE	1	2	RUMP	2	0	COAT	1	2	PACT	2	1	FERN	1	2
BRAT	1	2	WAKE	0	2	GROG	1	2	HOME	1	2	CYST	2	2	RAID	2	1
RIFT	2	2	CLOG	0	2	SHED	2	1	FOWL	0	2	SELF	2	1	POSE	2	2
PREY	2	0	RACK	2	2	PUCK	1	2	COCK	2	2	MEAT	2	2	AREA	2	2
RAMP	1	2	BALM	1	2	IDOL	2	0	CHEF	1	2	MOAT	2	0	CREW	2	2
PRIG	1	2	BIAS	1	2	SNAG	0	2	WICK	0	2	LOIN	1	2	NEON	1	2
HEAD	0	2	ONUS	0	2	UREA	0	2	FUND	1	2	NAME	0	2	RANK	0	2
HAZE	0	2	CANT	2	0	WRIT	0	2	KRIS	0	2	ACRE	2	0	RACE	2	0
GILT	2	0	NORM	2	2	TWIG	1	2	VINE	2	2	RUNG	0	2	PATH	2	0
GIRL	2	0	BUNK	1	2	MIRE	2	1	CRIB	1	2	WARD	2	0	STAG	0	2
DIET	2	2	SLAP	1	2	LUST	1	2	QUIZ	2	1	LEAF	1	2	NOTE	1	2
MIND	0	2	FOIL	1	2	HAFT	2	0	CRUX	2	0	POND	2	0	POST	2	2
SLOT	1	2	BEAN	0	2	HEAT	0	2	MALE	0	2	ROCK	0	2	MUSH	2	2
PITY	2	1	WAND	0	2	ROAN	0	2	PEEL	2	0	JACK	2	1	VOLE	1	2
PIER	2	1	WING	1	2	DRIP	1	2	FELT	2	2	LEAK	0	2	RENT	2	1
ROSE	1	2	VEST	2	2	ROPE	1	2	SIGN	0	2	YOLK	2	2	VOLT	2	0
HOST	1	2	JERK	2	0	CHIT	1	2	LIME	0	2	RIME	2	0	HEAP	0	2
LOBE	2	1	SHOE	0	2	FILE	2	1	JOKE	2	2	LIAR	0	2	SLED	0	2
VIEW	0	2	HULK	0	2	JOWL	1	2	RAFT	2	1	KITE	0	2	SALT	0	2
LUNG	2	0	PINE	1	2	LARD	2	1	OMEN	2	0	SEAT	2	1	RAKE	2	0
PEAL	2	2	DUNG	0	2	WISP	1	2	ZEAL	2	2	MINE	0	2	CLOT	2	0
GAOL	2	2	SUIT	2	1	GOLF	2	1	MINT	2	2	TOGS	0	2	SOUL	1	2
VIAL	2	0	BRIM	0	2	DEAN	0	2	DOSE	0	2	NAVE	2	2	MESH	2	2
DRAM	2	0	TRAP	2	0	FLUE	2	0	WISH	0	2	SACK	1	2	STEP	2	1
PLUG	2	0	ROBE	2	0	TOWN	0	2	FORT	2	1	LAWN	0	2	FLAX	0	2
MICE	2	1	STEM	0	2	BAND	1	2	HERO	1	2	MULE	2	0	LOFT	1	2
FUSE	1	2	RASP	1	2	WAVE	0	2	FATE	1	2	TIDE	0	2	FLAT	2	1
LYRE	2	1	SAFE	1	2	SECT	1	2	ADIT	1	2	WIND	1	2	COIL	2	2
CODE	1	2															

3 Ratings:

SKIT	0	3	BULK	2	3	BEEF	0	3	LISP	1	3	SHIN	0	3	BONE	1	3
WORD	1	3	LORD	2	3	LINT	1	3	CONE	3	1	EAST	1	3	DUMP	3	0
WEST	2	3	SAIL	2	3	PUNT	3	1	TONE	0	3	PELT	2	3	BOLT	3	0
POSY	3	1	PINK	3	3	DUTY	3	1	VENT	2	3	NAIL	3	0	SURF	2	3
COST	2	3	SOIL	1	3	YETI	2	3	TILE	0	3	BEAT	1	3	PAIL	2	3
ZONE	2	3	LINO	0	3	TOMB	3	2	FISH	0	3	PIKE	3	1	SEAL	1	3
SAGE	3	1	LIFT	3	1	FIRM	3	1	CROP	3	0	JEST	1	3	TWIN	3	2
CLUB	0	3	PEAT	3	2	LAMB	3	1	BALL	3	0	MASH	0	3	CRAB	3	2
RUNE	2	3	DISH	0	3	CAPE	2	3	FARE	0	3	MAZE	0	3	GUST	3	2
PICK	3	2	VASE	2	3	RUCK	0	3	MANE	3	2	SIDE	0	3	BAIT	3	0
SLAT	0	3	SLUM	0	3	SEAR	0	3	RIND	1	3	GANG	2	3	PERM	2	3
MIST	2	3	FIST	3	3	BELL	3	3	WIRE	3	1	SONG	0	3	LENS	1	3
PEST	2	3	VICE	2	3	BIKE	3	1	PACK	3	2	SLUG	1	3	JURY	3	2
PORT	3	1	FANG	1	3	SOAP	3	1									

Table A1.3 - Pilot 1: See page 300 for explanation.

A.1

4 Ratings:

CAST	3	4	INCH	1	4	CALF	1	4	NEWS	0	4	SHIP	1	4	PLOT	1	4
SCUM	0	4	TYRE	0	4	RING	1	4	ZANY	4	2	PARK	4	0	GALE	4	2
MAIL	4	3	MAST	2	4	GIFT	0	4	RUSK	2	4	FIRE	4	1	KELP	4	4
HUSK	0	4	MILE	1	4	DOCK	1	4	CAMP	1	4	MARE	0	4	LARK	0	4
GONG	0	4	VALE	4	3	TAIL	3	4	EVIL	4	2	TEAK	2	4	SILK	1	4
ISLE	1	4	TRIO	3	4	COLT	2	4	SINK	1	4	DUSK	1	4	TUNE	0	4
MASK	1	4	CENT	4	4	SERF	4	1	TURF	4	0	LINE	3	4	LOAF	0	4
ZEST	4	0	GOLD	0	4	NEST	3	4	CURE	4	0	CUSP	4	3	CASE	2	4
LIST	4	4	LAKE	4	4	MARK	0	4	CARE	2	4	UNIT	0	4	VERB	0	4
CITY	4	4	DUKE	2	4	TUSK	1	4	VEAL	1	4	WELT	0	4	CURB	4	2
PEAK	2	4	DECK	2	4	FEAR	0	4	YOKE	0	4	NECK	0	4	FAME	4	0
PART	4	1	CASK	1	4	VEIL	2	4	PANE	4	2	REST	4	0	GRIT	2	4
GLUE	2	4	RISK	1	4	MUSK	2	4	SITE	1	4	MILK	0	4	CULT	4	1
RAIL	4	2	CANE	0	4	GARB	0	4	SOLE	0	4	RINK	1	4	JUNK	4	4
SIZE	4	3															

Table A1.3 - Pilot 1: See page 300 for explanation.

Pilot 2: Brightness matching for dot matrix stimuli

It has been empirically demonstrated that the perceptual threshold of stimuli below a critical duration (approximately 100 ms) follows an intensity-duration reciprocity law (Bloch's Law, see page 18). One phenomenal correlate of this is that the apparent brightness of short duration stimuli is largely dependent on stimulus energy; ideally, for brightness equated stimuli of brief durations, a theoretical plot of Log_{10} intensity by Log_{10} duration would be expected show a slope of -1.

The purpose of this investigation was to validate the brightness matching procedures that were to be employed from time to time. Some of the data from this experiment were to be applied to later missing dot studies (Expts. 3, 4 & 5). The present brightness matching procedures were similar to those described by Servière *et al* (1977a) and Di Lollo (1979).

A.1

Method

The basic technique for brightness matching was as follows. Twelve dots, arranged in the form of a 3 by 4 rectangle (*referent*), were presented for a set duration of 100 ms at a constant dot luminance of 0.057 cd/m^2. 2 ms after the termination of the referent a similarly shaped stimulus (*target*) was displayed at a different location for any of 10 durations (these were 1, 10, 20, 30, 40, 50, 60, 70, 80 and 90 ms). The luminance of the target stimulus was adjusted at each exposure until S indicated that the referent and target stimuli had appeared to be of similar brightness. The ISI between referent and target was 2 ms.

Subjects

The same five subjects who were to take part in Expt. 3 also participated here.

Stimuli

The horizontal and vertical distances between adjacent dots were the same as those employed in Expt. 3. The right edge of the referent stimulus was offset 15 mm from the left of the (central) vertical display axis and the left edge of the target stimulus was offset 15 mm to the right.

Procedure

The apparatus, laboratory, lighting and other incidental conditions were the same as those described for Expts. 3 to 7.

Four trials were used to obtain a luminance value for each target duration. Each trial consisted of a

variable number of exposures where the target luminance was adjusted until a brightness match was indicated. Two of these trials were designated as *upwardly varying*. This meant that the target was obviously much dimmer than the referent on the first exposure. On subsequent exposures, target brightness was increased by 5 points (digital settings; see Appendix 3). When a near match was indicated by S, target luminance increments were reduced to 1 point. The other two trials were designated as *downwardly varying*. The procedure here was similar, except that the starting target luminance was adjusted to appear to be much brighter than the referent. The target luminance was then decremented for subsequent exposures. The order of upward and downward trials was randomized as were the target durations.

Subjects were instructed to give one of five responses after each exposure:- "much brighter", "slightly brighter", "same", "slightly dimmer" or "much dimmer". They triggered each exposure by means of a hand held button. Normally S's were allowed only one exposure at each target luminance; however on occasion this was extended to two exposures if difficulty was reported in making a judgement. Four practice trials were given to each subject prior to experimentation.

S's were given two minutes to adapt to the dark environment prior to the start of a series of four trials. After these were completed they were required to re-adapt to daylight conditions for a minimum of 5 minutes. In this way it was hoped that the level of dark adaptation

would be comparable for each target duration.

Results and Discussion

The mean dot luminance scores at each Sd2 are given in Table A1.4 (raw scores are given in Appendix 5). A graph of $\log_{10}$ luminance (cd/m^2) vs $\log_{10}$ Sd2 (ms) with a superimposed linear regression line is shown in Figure A1.1. For convenience of interpretation, a graph of the mean observed luminance values, as compared with the theoretical values is depicted in Figure A1.2.

The regression slope was -0.862 (r^2=0.974), and an ANOVA performed on the model showed that this was highly significant (F=1763.7; df= 1, 48; p<.001). Although this was somewhat shallower than the predicted slope, it was judged to be acceptable for experimental purposes.

Target Luminance (cd/m^2)	Std.Dev	Sd2
4.1724	0.9655	1
0.3462	0.0647	10
0.1956	0.0033	20
0.1666	0.0053	30
0.1462	0.0075	40
0.1258	0.0038	50
0.1086	0.0049	60
0.0950	0.0062	70
0.0806	0.0071	80
0.0690	0.0094	90

Table A1.4 - Pilot 2: Mean dot luminance of target stimulus when brightness matched against a 100 ms referent stimulus which was projected at 0.057 cd\m².

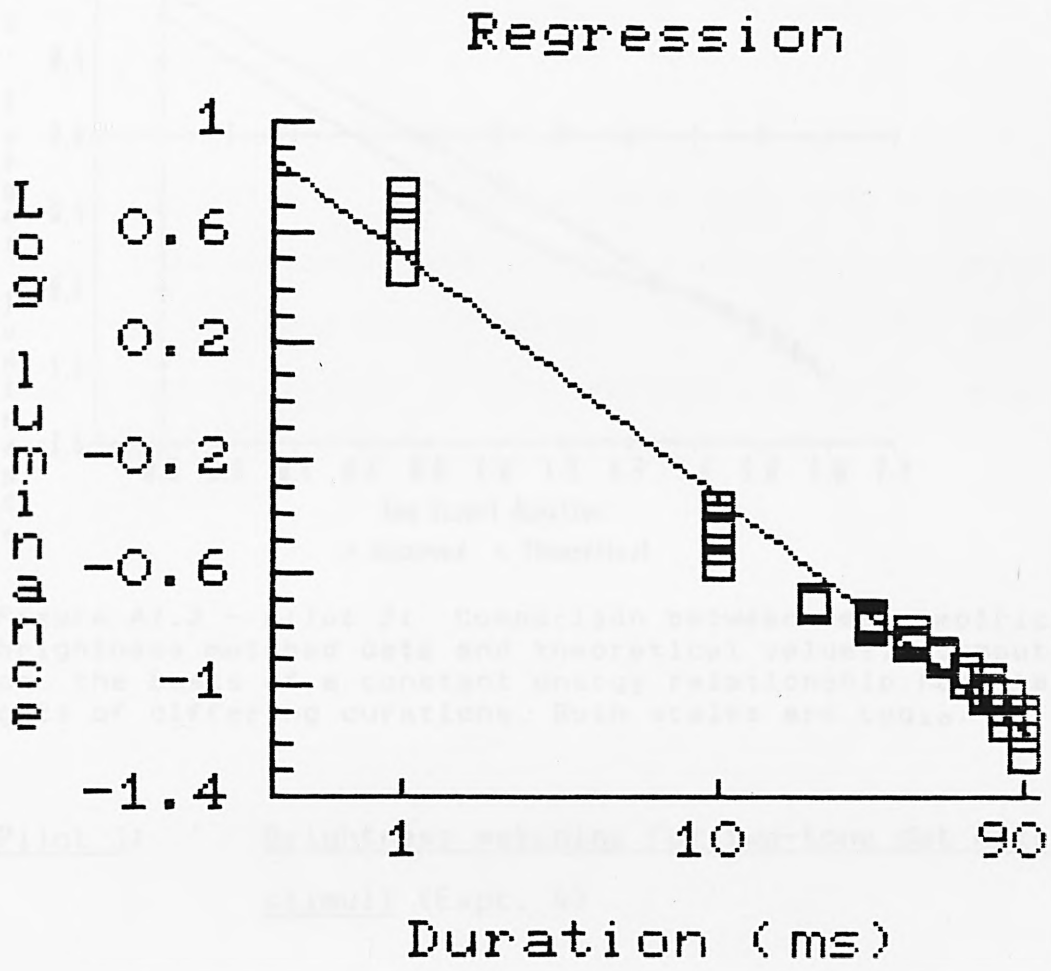


Figure A1.1 - Pilot 2: Regression on observations of apparent brightness equated stimuli as a function of target duration. Both scales are Log_{10}.

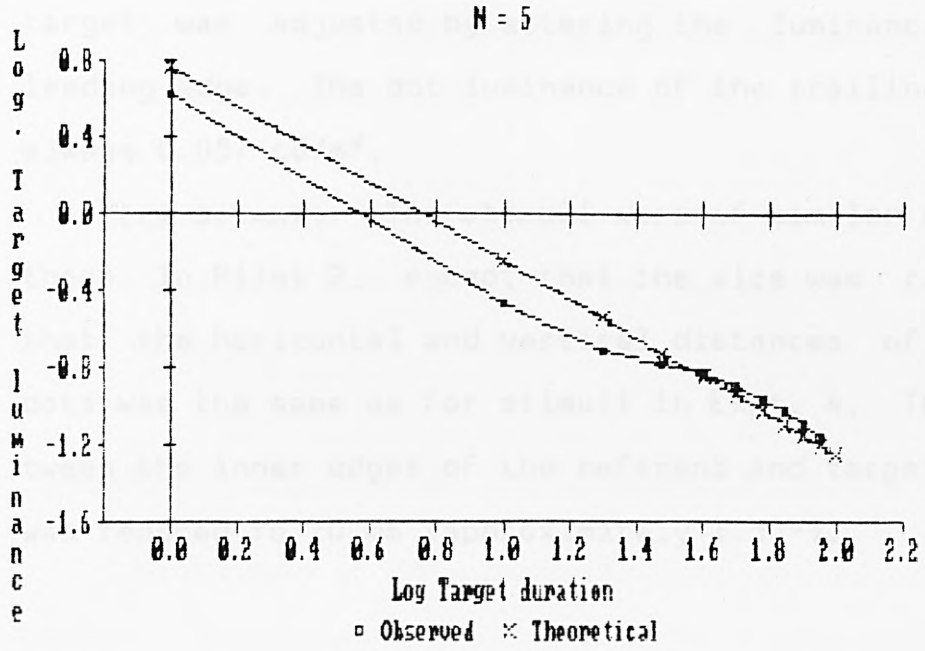


Figure A1.2 - Pilot 2: Comparison between mean empirical brightness matched data and theoretical values, computed on the basis of a constant energy relationship for targets of differing durations. Both scales are Log_{10}.

Pilot 3: Brightness matching for two-tone dot matrix stimuli (Expt. 4)

This investigation was used to equate the brightness of four stimulus field conditions that were to be employed in Expt. 4. These were the high S2 luminance condition in Control 1 and the three levels of E.set (see Expt. 4). The method and procedures were similar to those described for Pilot 2 (see above), with the following differences:

(1) Conditions: The referent stimulus duration was 150 ms and was presented at a dot luminance of 0.429 cd/m². The three target conditions had the same temporal parameters as S2 in the three levels of E.set (see Expt.

4). Within each trial, the apparent brightness of the target was adjusted by altering the luminance of its leading edge. The dot luminance of the trailing edge was always 0.057 cd/m^2.

(2) Stimuli: The stimuli were of similar design to those in Pilot 2, except that the size was reduced so that the horizontal and vertical distances of adjacent dots was the same as for stimuli in Expt. 4. The gap between the inner edges of the referent and target stimuli was reduced to 20 mm (approximately 1.53°).

A.1

Subjects

The same four subjects who were to participate in Expt. 4 were tested here.

Results

The raw data are displayed in Appendix 5. The mean dot luminance scores were used in the appropriate conditions in Expt. 4 (see Table 2.10).

Pilot 4: Brightness matching tests for Expt. 6.

The purpose of this investigation was to equate the apparent brightness of all the stimuli that were to be presented in Expt. 6. In the present study, subjects only participated in those conditions which were relevant to Expt. 6 (hence only 3 S's participated in all target duration conditions).

Most aspects were the same as in Pilot 3 except for the stimulus intensity and duration parameters (all the present stimuli were constant intensity within exposures). The referent stimulus duration was 1 ms and its dot luminance was 5.39 cd/m^2. The ISI was always 40 ms and the four target durations were 10, 30, 50 and 100 ms.

Results

The scores for each subject are shown in Table A1.5. These values were used in the appropriate conditions in Expt. 6.

A.1

Subject	Target Dot Luminance (cd/m²)			
	Sd2=10 ms.	Sd2=30 ms.	Sd2=50 ms.	Sd2=100 ms.
DRL	-	-	0.114	0.074
TFP	-	-	0.097	0.049
IRM	-	-	0.114	0.066
SDA	0.528	0.175	0.154	0.091
DFS	0.661	0.183	0.162	0.091
RAV	0.661	0.167	0.114	0.057

Table A1.5 - Pilot 4: S2 dot luminance values. These values were based on the mean target luminance values, which were obtained over 4 trials for each subject, at each target duration (Sd2). The referent stimulus duration was 1 ms and its dot luminance was 5.39 cd/m². These results were applied to Expt. 6.

Pilot 5: Brightness matching for Expt. 7

This test was required in order to match the brightness of each of the long and short S2 durations in both the high and low (S2) intensity conditions in Expt. 7.

The procedure for this was the same as in Pilot 4 except that there were two referent stimulus conditions and only one target duration (100 ms). The referent duration was always 10 ms and this was presented at 2.37 and 0.162 cd/m² (these represent the high and low intensity conditions respectively).

The two subjects who were to undertake Expt. 7 were also participants in this test.

Results and Data Application

The two subjects gave similar scores in all conditions. These results were applied directly to Expt. 7 and all the S2 dot luminances which were used in that experiment are displayed in Table 3.5.

The results of the present study were used in the

high and low S2 brightness conditions in Expt. 7. The intensity values for the medium condition in Expt. 7 were taken from the mean results (for DFS and RAV) of Pilot 4 (see Table A1.5).

APPENDIX 2: STIMULI FOR EXPERIMENTS 1 & 2.

Experiment 1:

List 1	List 2	List 3	List 4	List 5	List 6	List 7
GEAR	OVEN	OATH	HERD	DUNE	HOSE	CAGE
CAVE	CORN	BLOW	TAXI	CUBE	FUEL	HARP
BURN	KNOT	SHOT	GATE	SODA	HAWK	ZINC
DENT	DUEL	GULF	ARAB	BENT	BALD	PILE
COAL	MAID	ITCH	TUBE	PLAY	HALO	SHOW
HOPE	CLAY	PRAM	HYMN	IDEA	WIFE	FOUR
TOUR	BROW	TIME	LACK	LAMP	SAND	ATOM
HIND	VOID	ARMY	GLOW	BORE	LOVE	LINK
BACK	DEAL	DICE	LEAD	WOLF	WORM	CASH
GRAM	YEAR	BUSH	SEAM	FORM	YARD	GAME
TYPE	CAKE	TACK	FACE	CALM	COPY	JADE
USER	PALM	HORN	HACK	ARCH	ROAD	STEW

List 8	List 9
CLAW	HAND
ZERO	CHAP
BEER	RUIN
FIVE	OVAL
HALF	HOUR
PEAR	MYTH
COIN	DEBT
DAMP	KIND
BODY	WHIM
TAPE	HARE
BAIL	DRUG
FEUD	BOMB

A.2

Experiment 2:

List 1	List 2	List 3	List 4
HILT	BOWL	ECHO	PORE
AGED	GOAL	AXLE	PLUM
PROW	LIMP	BLUR	LURE
HAIL	HIVE	WHIP	HUNT
DUCT	WART	CHOP	PAGE
FIFE	SINE	ALTO	CHUM
STUB	FOLD	BOAT	STUD
MEMO	RAND	SNOB	EXIT
FLEX	WEIR	LUMP	DARE
TERM	LAIR	TUBA	CROW
FAIR	CZAR	ITEM	FRET
LOAD	SNOW	STAR	LAND
SAKE	FILM	BASE	HOLE

List 5	List 6	List 7	List 8
LORE	MINE	SEAT	HEAP
WAND	RASP	RACK	BAND
SHED	LACE	TICK	WISP
FOWL	QUIZ	YOLK	LOBE
RAID	RENT	RIFT	NOSE
DIGS	PEAL	LASH	SLOT
FLAW	DRAM	HULK	RIOT
SECT	SACK	POLE	LEAK
VINE	SNAG	DISC	WARD
COAT	RUST	BITE	KITE
FILE	FLAT	ROCK	CLIP
ROSE	HEAT	JOKE	BEAN
PATH	SHOE	SIGN	DATE

APPENDIX 3: TECHNICAL DETAILS

Software

The overall running of all experiments, including stimulus selection and file handling, was controlled by BASIC programs that ran on the PET. However, programs that are written in this language operate too slowly to be of use for the physical control of stimulus presentations. For this reason, all display presentations, including timings, were controlled by machine code programs that had been written in 6502 Assembly code. With this programming language it was possible to obtain reliable timing resolutions to 10^{-5} seconds.

All programs were specially written for the present research by the author.

Display apparatus

This section gives details about the display characteristics, control and calibration of the two types of display device which were employed in the research for this thesis:

1. PET display monitor *(used in Experiments 1, 2 & 8):*

This was a non-interlaced display operating at a refresh frequency of 60 Hz. Timings were effected by accessing the vertical screen pulse that occurred at

regular intervals of approximately 16.67 ms.

Stimulus intensity could not be altered under program control but it could be adjusted manually. Adjustments had to be made from time to time in order to maintain constant luminance conditions within experiments.

The time required to place the large stimuli (used in Expts. 1 & 2) on the screen was approximately 2.5 ms. For the smaller array stimuli that were used in Expt. 8, this period was reduced to approximately 832 μs.

With the aid of test equipment (described below) it was ascertained that stimuli which were presented at a mean luminance of 37 cd/m^2 reached full intensity virtually instantaneously. At stimulus offset, luminance decayed quickly down to 25% of its original value in 2.5 ms. From then on the decay curve appeared to be exponential with a half-life of approximately 2.5 ms. As mentioned in the body of the text, the filters moderated the intensity of this afterglow.

2. Tektronix 604 A display *(Used in Expts. 3 to 7)*

The PET was able to fully control stimulus intensity and spatial positioning on this display device (which had a frequency response in the order of less than 1 μs).

Spatial coordinates of stimuli were controlled by analogue voltages applied to X and Y inputs and stimulus luminance was determined by analogue voltages to the Z input. All these voltages were controlled by the PET which was able to send digital values ranging from 0 to

255 to any of the appropriate channels. These values were converted to analogue voltages, for compatibility with the display device, via a purpose built four channel digital to analogue converter (D to A converter) with a response time of less than 1 μs. In order to ensure complete compatibility between the D to A converter and the display device, a three channel potential divider was linked between them. This enabled the system to be adjusted and calibrated on a day to day basis.

Luminance calibrations

The luminance of single dots (dot luminance) was measured with a Photo Research Spectra Spotmeter UBD- ½° at a distance of 710 mm from the display screen (i.e. the usual subject viewing distance).

The relationships between digital values and dot luminance are given in Table A3.1. It should be noted, however, that the figures for dot luminance are not the true mean luminance values. The angular discrepancy between individual dots and the field of view of the spotmeter meant that it was impossible to obtain, by direct means, the true mean luminance values. However, these values could be calculated on the basis of area of display surface that was encompassed by the spotmeter's field of view, divided by the area of a single dot. Thus, based on the ½° view of the spotmeter and 1 mm diameter of a single dot (this diameter accorded well with the claims of the manufacturer), the mean stimulus luminance was calculated to be 38.3899 multiplied by dot luminance. These values are shown in the mean luminance columns in

Table A3.1 but since they may be open to a high degree of inaccuracy (a small error in the difficult to measure dot diameter would have resulted in a large error in the calculated mean stimulus luminance), only the dot luminances are given in the body of the text.

In Experiments 3 to 7, each stimulus field (i.e. 12 dots) was fully presented in 1 ms and refreshed at the rate of 1 KHz.

Day to day calibration

For day to day luminance calibration and timing validation a silicon photodiode with integrated amplifier (RS. No. 308-067) connected to a calibrated Scopex Instruments oscilloscope Type 4D-25 set to automatic trigger was used. The photodiode was attached to the correct location on the display screen with a seal of 'blu-tak' putty (the screen was easily cleaned afterwards with surgical alcohol). Upon stimulus presentation a visual trace of dot luminance could be analysed. The height of the trace indicated the luminance of the dot and any discrepancy from the expected height could be eradicated by adjusting the Z channel of the potential divider.

It may be noticed that there are two circumstances where the claimed dot luminance values do not match those that are shown in Table A3.1. One circumstance is where the dot luminance of the fixation stimulus is given. This signal was the only one that was generated under BASIC program control and it was found that its intensity did not conform to the luminance scale that was associated with machine code generated stimuli. The technical rea-

sons for this anomaly have not been ascertained by the writer.

The second circumstance is when the dot luminance values of 1 ms displays are shown. The reason for this is that the display intensity was always 10 % lower on the first refresh than on subsequent refreshes. Thus, the reported dot luminance of 1 ms stimuli is always 10% lower than the values presented in Table A3.1. For longer stimulus durations, this discrepancy was considered to be negligible and has therefore been ignored.

The above described test procedures were also useful for monitoring the stimulus presentation in Expts. 1, 2 and 8, where the inbuilt PET computer monitor was the display device. The validity of timing operations was ascertained by counting the number of screen pulses within a stimulus presentation. Each pulse reflected the operation of a single screen refresh scan which occurred approximately every 16.67 ms. Thus, a stimulus which contained six pulses was determined to have been presented for 100 ms.

A.3

Digital Value	Dot Luminance (cd\m²)	*Mean Luminance (cd/m²)	Digital Value	Dot Luminance (cd\m²)	*Mean Luminance (cd/m²)
145	0.003	0.115	180	0.222	8.523
146	0.004	0.154	181	0.241	9.252
147	0.004	0.154	182	0.265	10.173
148	0.005	0.192	183	0.302	11.594
149	0.007	0.269	184	0.353	13.552
150	0.010	0.384	185	0.429	16.469
151	0.012	0.461	186	0.528	20.270
152	0.015	0.576	187	0.661	25.376
153	0.019	0.729	188	0.827	31.748
154	0.023	0.883	189	1.027	39.426
155	0.027	1.037	190	1.279	49.101
156	0.033	1.267	191	1.573	60.387
157	0.038	1.459	192	2.000	76.780
158	0.044	1.689	193	2.370	90.984
159	0.049	1.881	194	2.770	106.340
160	0.057	2.188	195	3.230	123.999
161	0.066	2.534	196	3.800	145.882
162	0.074	2.841	197	4.290	164.693
163	0.082	3.148	198	4.840	185.807
164	0.091	3.493	199	5.380	206.538
165	0.097	3.724	200	5.990	229.956
166	0.105	4.031			
167	0.114	4.376			
168	0.123	4.722			
169	0.130	4.991			
170	0.139	5.336			
171	0.145	5.567			
172	0.154	5.912			
173	0.162	6.219			
174	0.167	6.411			
175	0.175	6.718			
176	0.183	7.025			
177	0.192	7.371			
178	0.198	7.601			
179	0.207	7.947			

*The values in this column were calculated on the basis of dot luminance x 38.3899. This gave a rough guide to the true mean display luminance.

Table A3.1 - Experiments 3 to 7: The relationship between digital settings on the PET, dot luminance measurements and calculated mean luminance. See text for further details.

Stimulus decay attributes

One disadvantage with generating visual stimuli on cathode ray display apparatus has sometimes been that stated stimulus durations have been rendered inaccurate

due to residual screen phosphorescence. In some cases, conclusions based on experiments with this type of display apparatus have been completely invalidated (see Irwin *et al*, 1983).

In the present thesis, any small residual screen luminance would not have posed a serious threat to any general conclusions arising from the reported empirical work. Nevertheless, since some of the experiments depended on fine duration differences, it was of interest to determine the validity of durations:

When screen traces of single dots were presented at 5.99 cd/m² (dot luminance), tests with the above described equipment determined that dot intensity increased from zero to its maximum value virtually instantaneously. Immediately thereafter the intensity decayed so that 300 μs later the mean luminance was 0.114 cd/m². 700 μs after this the dot luminance was 0.027 cd/m² and 2 ms after the initial moment of decay the dot intensity went completely undetected by the test instruments.

Further timing tests

The above described tests were able to provide rough validation of display timing routines. However, for a more accurate analysis it was necessary to temporarily alter some machine code routines to output signals to an external digital timer (Malden Electronics Digital Timer 8816) via pins 3 and 4 on the PET parallel user port. The commands were inserted at the beginning and end of the timing routines to be tested. When correctly placed these commands could in no way affect the timing routines them-

selves. The object of the exercise was to signal the external timer to start counting at the start of a soft-timed period and to cease operation on completion of the routine.

The experimental system was calibrated using this technique and soft-timed reliability was found to be virtually 100 %. Each refresh of 12 dots was determined to take 1.005 ms and, since this error was additive, the duration for a programmed 100 ms display was, in fact, 100.5 ms (this was empirically confirmed). This small deviation from the reported duration values was judged to be acceptable.

APPENDIX 4: STATISTICAL ANALYSES

Experiment 1; 3 way ANOVA, repeated measures on Sd1 and Sd2 only. Dependent variable is % correct score:

SOURCE	SUM OF SQUARES	DF	MS	F	p
between S's	125535.48	53			
ISI	45131.37	2	22565.484	14.313	<.001
error a	80404.11	51	1576.551		
within S's	112104.95	432			
Sd1	3150.75	2	1575.375	10.676	<.001
ISIxSd1	747.21	4	186.804	1.266	n.s.
error b	15050.84	102	147.558		
Sd2	48974.21	2	24487.107	130.113	<.001
ISIxSd2	2016.69	4	504.173	2.679	<.05
error c	19196.25	102	188.199		
Sd1xSd2	506.06	4	126.515	1.213	n.s.
ISIxSd1xSd2	1079.94	8	134.993	1.294	n.s.
error bc	21383.00	204	104.328		
TOTAL	379.297	485			

Experiment 2; 2 way ANOVA, repeated measures on both factors. Dependent variable is % correct score:

SOURCE	SUM OF SQUARES	DF	MS	F	p
Sd2	58.455	1	58.455	1.156	n.s.
S2*	1568.700	1	1568.700	13.304	<.025
S's	5345.697	7	763.671		
S'sxSd2	353.986	7	50.570		
S'sxS2	825.362	7	117.909		
Sd2xS2	24.325	1	24.325	0.316	n.s.
S'sxSd2xS2	538.374	7	76.911		
TOTAL	8714.899	31			

* (S2) Mask factor (superposition or bar).

A.4

Experiment 3; 1 way ANOVA. Dependent variable is % correct score:

SOURCE	SUM OF SQUARES	DF	MS	F	p
Sd2	9476.55	3	3158.850	32.856	<.001
S's	874.70	4	218.675	2.275	n.s.
Sd2 x S's	1153.70	12	96.142		
TOTAL	11504.95	19			

Experiment 3; 1 way ANOVA. Depentent variable is percentage of errors in the 1st field:

SOURCE	SUM OF SQUARES	DF	MS	F	p
Sd2	1463.0175	3	487.673	2.123	n.s.
S's	766.6350	4	191.659	0.835	n.s.
Sd2 x S's	2756.1450	12	229.679		
TOTAL	4985.7975	19			

Experiment 4; 1 way ANOVA (repeated measures) on Control 1 data. Dependent variable is % correct score:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	826.917	3	275.639	3.907	.073
C1*	324.667	2	162.333	2.301	.181
S's x C1	423.333	6	70.556		
TOTAL	1574.917	11			

* Control 1

A.4

Experiment 4; Page's L test on intensified conditions (E.set). Dependent variable is % correct score:

k = 3, N = 4.

Predicted u:	1	2	3
Flash dur:	50	30	10
Subject 1.	63(1)	69(2)	76(3)
Subject 2.	58(2)	52(1)	78(3)
Subject 3.	68(1)	88(2)	98(3)
Subject 4.	48(1)	62(3)	55(2)
R:	5	8	11

L = ΣRu = 5 + 16 + 33 = 54, $p<0.05$.

Experiment 4; Page's L test on non-intensified but variable Sd2 conditions (Control 2). Dependent variable is % correct score:

k = 3, N = 4.

Predicted u:	1	2	3
Sd2:	50	30	10
Subject 1.	97(1.5)	97(1.5)	98(3)
Subject 2.	81(1)	84(2)	85(3)
Subject 3.	95(1)	99(3)	98(2)
Subject 4.	81(3)	78(2)	77(1)
R:	6.5	8.5	9

L = ΣRu = 6.5 + 17 + 27 = 50.5 - n.s.

A.4

Experiment 5; 3 way ANOVA, repeated measures on all factors. Dependent variable is % correct score:

N.B. Conditions 1 & 6 are not included in this analysis.

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	10813.167	5	2162.633		
F1	5808.000	1	5808.000	15.258	<.025
F2	208.333	1	208.333	9.065	<.05
F3	2028.000	1	2028.000	12.184	<.025
S'sxF1	1903.250	5	380.650		
S'sxF2	114.917	5	22.983		
S'sxF3	832.250	5	166.450		
F1xF2	24.083	1	24.083	1.083	n.s.
F1xF3	140.083	1	140.083	2.341	n.s.
F2xF3	44.083	1	44.083	2.137	n.s.
S'sxF1xF2	111.167	5	22.233		
S'sxF1xF3	299.167	5	59.833		
S'sxF2xF3	103.167	5	20.633		
F1xF2xF3	12.000	1	12.000	0.217	n.s.
S'sxF1xF2xF3	276.250	5	55.250		
TOTAL	22717.917	47			

F1 - Factor 1 = Total duration ([2] - 75 or 95 ms)
F2 - Factor 2 = Sd1 or Sd2 ([2] - 1st or 2nd field)
F3 - Factor 3 = Stimulus duration of independent variable in F2 ([2] - 30 or 50 ms).

N.B. F3 was confounded with ISI.

Experiment 5; 2 way ANOVA, repeated measures for SOA and nominal Sd1 factor. Dependent variable is % correct score. This analysis only includes conditions 1, 2, 3, 6, 7 & 8:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	9061.333	5	2253.701		
SOA	4312.111	1	4312.111	23.178	<.01
Sd1	4656.167	2	2328.083	17.213	<.001
S'sxSOA	930.222	5	186.044		
S'sxSd1	1352.500	10	135.250		
SOAxSd1	147.722	2	73.861	1.063	n.s.
S'sxSOAxSd1	694.944	10	69.494		
TOTAL	21155.000	35			

N.B. Sd1 was confounded with ISI.

A.4

Experiment 5; 2 way ANOVA, repeated measures for SOFFA and nominal Sd2 factor. Dependent variable is % correct score. This analysis only includes conditions 1, 4, 5, 6, 9 & 10:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	10173.222	5	2034.644		
SOFFA	5088.444	1	5088.444	43.599	<.01
Sd2	2838.722	2	1419.361	21.771	<.001
S'sxSOFFA	583.556	5	116.711		
S'sxSd2	651.944	10	65.194		
SOFFAxSd2	37.389	2	18.694	0.265	n.s.
S'sxSOFFAxSd2	704.611	10	70.461		
TOTAL	20077.889	35			

N.B. Sd2 was confounded with ISI.

Experiment 6; 2 way ANOVA, repeated measures on both factors in Experimental conditions. Dependent variable is % correct score:

SOURCE	SUM OF SQUARES	DF	MS	F	p
Sd2	1096.222	2	548.111	6.207	<.025
Report	568.028	1	568.028	2.277	n.s.
S's	1664.472	5	332.894	13.049	<.001
S'sxSd2	883.111	10	88.311		
S'sxReport	1247.139	5	249.428		
ReportxSd2	11596.222	2	5798.111	227.278	<.001
S'sxRep.xSd2	255.111	10	25.511		
TOTAL	17310.306	35			

Experiment 6; 1 way ANOVA on data from Control condition. Dependent variable is % correct score:

SOURCE	SUM OF SQUARES	DF	MS	F	p
Sd2	211.111	2	105.556	0.590	n.s.
S's	656.944	5	131.389	0.735	n.s.
S'sxSd2	1788.889	10	178.889		
TOTAL	2656.944	17			

A.4

Experiment 6; 1 way ANOVA. Dependent variable is percentage of errors in the 1st field:

SOURCE	SUM OF SQUARES	DF	MS	F	p
Sd2	3920.031	2	1960.015	4.467	<.05
S's	3568.645	5	713.729	1.627	n.s.
S'sxSd2	4387.645	10	438.765		
TOTAL	11876.3201	17			

Experiment 6; 2 way ANOVA, repeated measures. Dependent variable is % correct score in the missing dot report condition only:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	197.911	5	39.582		
Sd2	804.544	2	202.272	42.566	<.001
Letter	134.422	9	14.936	6.284	<.001
S'sxSd2	47.522	10	4.752		
S'sxLetter	106.978	45	2.377		
Sd2xLetter	97.678	18	5.427	3.466	<.001
S'sxSd2xLetter	140.922	90	1.566		
TOTAL	1529.978	179			

A.4

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % correct score in the single letter report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	8446.484	7	1206.641		
F1	1097.266	1	1097.266	88.176	<.001
F2	9144.141	1	9144.141	49.134	<.001
F3	1650.391	1	1650.391	19.368	<.01
S'sxF1	87.109	7	12.444		
S'sxF2	1302.734	7	186.105		
S'sxF3	596.484	7	85.212		
F1xF2	425.391	1	425.391	3.188	n.s.
F1xF3	172.266	1	172.266	4.601	n.s.
F2xF3	19.141	1	19.141	0.482	n.s.
S'sxF1xF2	933.984	7	133.426		
S'sxF1xF3	262.109	7	37.444		
S'sxF2xF3	277.734	7	39.676		
F1xF2xF3	0.391	1	0.391	0.004	n.s.
S'sxF1xF2xF3	758.984	7	108.426		
TOTAL	25174.609	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % transposition score in the single letter report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	6410.938	7	915.848		
F1	451.563	1	451.563	8.190	<.025
F2	6400.000	1	6400.000	41.195	<.001
F3	826.563	1	826.563	12.553	<.01
S'sxF1	385.938	7	55.134		
S'sxF2	1087.500	7	155.357		
S'sxF3	460.938	7	65.848		
F1xF2	225.000	1	225.000	1.448	n.s.
F1xF3	76.563	1	76.563	0.955	n.s.
F2xF3	156.250	1	156.250	2.692	n.s.
S'sxF1xF2	1087.500	7	155.357		
S'sxF1xF3	560.938	7	80.134		
S'sxF2xF3	406.250	7	58.036		
F1xF2xF3	25.000	1	25.000	0.275	n.s.
S'sxF1xF2xF3	637.497	7	91.071		
TOTAL	19198.438	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

A.4

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % intrusion score in the single letter report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	343.359	7	49.051		
F1	141.016	1	141.016	3.515	n.s.
F2	244.141	1	244.141	26.198	<.01
F3	141.016	1	141.016	6.333	<.05
S'sxF1	280.859	7	40.123		
S'sxF2	65.234	7	9.319		
S'sxF3	155.859	7	22.266		
F1xF2	31.641	1	31.641	0.732	n.s.
F1xF3	19.141	1	19.141	0.443	n.s.
F2xF3	66.016	1	66.016	1.899	n.s.
S'sxF1xF2	302.734	7	43.248		
S'sxF1xF3	302.734	7	43.248		
S'sxF2xF3	243.359	7	34.766		
F1xF2xF3	19.141	1	19.141	0.462	n.s.
S'sxF1xF2xF3	290.234	7	41.462		
TOTAL	2646.484	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % correct score of direct targets in the full row report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	7212.500	7	1030.357		
F1	225.000	1	225.000	3.500	n.s.
F2	4225.000	1	4225.000	43.018	<.001
F3	976.562	1	976.563	22.906	<.001
S'sxF1	450.000	7	64.286		
S'sxF2	687.500	7	98.214		
S'sxF3	298.438	7	42.634		
F1xF2	506.250	1	506.250	11.118	<.025
F1xF3	39.063	1	39.063	0.845	n.s.
F2xF3	76.563	1	76.563	0.896	n.s.
S'sxF1xF2	318.750	7	45.536		
S'sxF1xF3	323.438	7	46.205		
S'sxF2xF3	598.438	7	85.491		
F1xF2xF3	39.063	1	39.063	0.159	n.s.
S'sxF1xF2xF3	1723.438	7	246.205		
TOTAL	17700.0000	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

A.4

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % transposition score of direct targets in the full row report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	2787.500	7	398.214		
F1	156.250	1	156.250	1.667	n.s.
F2	1600.000	1	1600.000	8.220	<.025
F3	564.063	1	564.063	8.566	<.025
S'sxF1	656.250	7	93.750		
S'sxF2	1362.500	7	194.643		
S'sxF3	460.938	7	65.848		
F1xF2	225.000	1	225.000	2.377	n.s.
F1xF3	39.063	1	39.063	0.264	n.s.
F2xF3	264.063	1	264.063	3.449	n.s.
S'sxF1xF2	662.500	7	94.643		
S'sxF1xF3	1035.938	7	147.991		
S'sxF2xF3	535.938	7	76.563		
F1xF2xF3	1.563	1	1.563	0.020	n.s.
S'sxF1xF2xF3	548.434	7	78.348		
TOTAL	10900.000	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % intrusion score of direct targets in the full row report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	1731.250	7	247.321		
F1	6.250	1	6.250	0.175	n.s.
F2	625.00	1	625.000	2.767	n.s.
F3	56.250	1	56.250	0.444	n.s.
S'sxF1	250.000	7	35.714		
S'sxF2	1581.250	7	225.893		
S'sxF3	887.500	7	126.786		
F1xF2	56.250	1	56.250	1.432	n.s.
F1xF3	156.250	1	156.250	3.500	n.s.
F2xF3	56.250	1	56.250	1.167	n.s.
S'sxF1xF2	275.000	7	39.286		
S'sxF1xF3	312.500	7	44.643		
S'sxF2xF3	337.500	7	48.214		
F1xF2xF3	56.250	1	56.250	0.955	n.s.
S'sxF1xF2xF3	412.500	7	58.929		
TOTAL	6800.000	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

A.4

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % correct score of indirect targets in the full row report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	5217.188	7	745.313		
F1	0.000	1	0.000	0.000	n.s.
F2	1806.250	1	1806.250	105.433	<.001
F3	234.473	1	234.473	6.246	<.05
S'sxF1	133.203	7	19.029		
S'sxF2	119.922	7	17.132		
S'sxF3	262.793	7	37.542		
F1xF2	1.563	1	1.563	0.054	n.s.
F1xF3	28.223	1	28.223	1.070	n.s.
F2xF3	7.910	1	7.910	0.248	n.s.
S'sxF1xF2	201.172	7	28.739		
S'sxF1xF3	184.668	7	26.381		
S'sxF2xF3	222.949	7	31.850		
F1xF2xF3	0.098	1	0.098	0.002	n.s.
S'sxF1xF2xF3	379.199	7	54.171		
TOTAL	8799.609	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % transposition score of indirect targets in the full row report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	2040.625	7	291.518		
F1	11.816	1	11.816	0.590	n.s.
F2	1203.223	1	1203.223	34.402	<.001
F3	56.250	1	56.250	3.083	n.s.
S'sxF1	140.137	7	20.020		
S'sxF2	244.824	7	34.975		
S'sxF3	127.734	7	18.248		
F1xF2	3.516	1	3.516	0.082	n.s.
F1xF3	21.973	1	21.973	1.834	n.s.
F2xF3	2.441	1	2.441	0.083	n.s.
S'sxF1xF2	299.219	7	42.746		
S'sxF1xF3	83.887	7	11.984		
S'sxF2xF3	205.762	7	29.395		
F1xF2xF3	3.516	1	3.516	0.104	n.s.
S'sxF1xF2xF3	235.936	7	33.705		
TOTAL	4680.859	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

A.4

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is % intrusion score of indirect targets in the full row report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	1087.109	7	155.301		
F1	11.816	1	11.816	0.788	n.s.
F2	61.035	1	61.035	2.813	n.s.
F3	61.035	1	61.035	2.416	n.s.
S'sxF1	104.981	7	14.997		
S'sxF2	151.856	7	21.694		
S'sxF3	176.856	7	25.265		
F1xF2	9.766	1	9.766	2.917	n.s.
F1xF3	0.391	1	0.391	0.026	n.s.
F2xF3	1.563	1	1.563	0.099	n.s.
S'sxF1xF2	23.438	7	3.348		
S'sxF1xF3	106.250	7	15.179		
S'sxF2xF3	110.547	7	15.792		
F1xF2xF3	2.441	1	2.441	0.107	n.s.
S'sxF1xF2xF3	159.666	7	22.809		
TOTAL	2068.750	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is number of horizontally adjacent transpositions in the full row report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	149.859	7	21.408		
F1	1.266	1	1.266	0.187	n.s.
F2	28.891	1	28.891	3.764	<.1
F3	0.391	1	0.391	0.053	n.s.
S'sxF1	47.359	7	6.766		
S'sxF2	53.734	7	7.676		
S'sxF3	51.234	7	7.319		
F1xF2	0.141	1	0.141	0.064	n.s.
F1xF3	6.891	1	6.891	1.679	n.s.
F2xF3	5.641	1	5.641	1.197	n.s.
S'sxF1xF2	15.484	7	2.212		
S'sxF1xF3	28.734	7	4.105		
S'sxF2xF3	32.984	7	4.712		
F1xF2xF3	21.391	1	21.391	5.498	<.1
S'sxF1xF2xF3	27.234	7	3.891		
TOTAL	471.234	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

A.4

Experiment 8; 3 way ANOVA, repeated measures. Dependent variable is number of vertically adjacent transpositions in the full row report condition:

SOURCE	SUM OF SQUARES	DF	MS	F	p
S's	703.484	7	100.498		
F1	31.641	1	31.641	12.316	<.01
F2	244.141	1	244.141	12.385	<.01
F3	50.766	1	50.766	3.999	<.1
S'sxF1	17.984	7	2.569		
S'sxF2	137.984	7	19.712		
S'sxF3	88.859	7	12.694		
F1xF2	0.391	1	0.391	0.022	n.s.
F1xF3	0.141	1	0.141	0.017	n.s.
F2xF3	11.391	1	11.391	0.930	n.s.
S'sxF1xF2	123.734	7	17.676		
S'sxF1xF3	57.484	7	8.212		
S'sxF2xF3	85.734	7	12.248		
F1xF2xF3	1.266	1	1.266	0.093	n.s.
S'sxF1xF2xF3	94.859	7	13.551		
TOTAL	1649.859	63			

F1 is Sd1
F2 is ISI
F3 is Sd2

APPENDIX 5: RAW DATA

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
1	79.1675	16.7	16.7	33.3
2	89.5825	16.7	16.7	33.3
3	85.4175	16.7	16.7	33.3
4	70.8325	16.7	16.7	33.3
5	75.0000	16.7	16.7	33.3
6	87.5000	16.7	16.7	33.3
7	87.5000	16.7	16.7	33.3
8	91.6675	16.7	16.7	33.3
9	72.9175	16.7	16.7	33.3
10	89.5825	16.7	16.7	33.3
11	83.3325	16.7	16.7	33.3
12	83.3325	16.7	16.7	33.3
13	77.0825	16.7	16.7	33.3
14	68.7500	16.7	16.7	33.3
15	83.3325	16.7	16.7	33.3
16	83.3325	16.7	16.7	33.3
17	89.5825	16.7	16.7	33.3
18	89.5825	16.7	16.7	33.3
1	83.3325	50.0	16.7	33.3
2	56.2500	50.0	16.7	33.3
3	56.2500	50.0	16.7	33.3
4	68.7500	50.0	16.7	33.3
5	89.5825	50.0	16.7	33.3
6	77.0825	50.0	16.7	33.3
7	83.3325	50.0	16.7	33.3
8	79.1675	50.0	16.7	33.3
9	83.3325	50.0	16.7	33.3
10	70.8325	50.0	16.7	33.3
11	93.7500	50.0	16.7	33.3
12	91.6675	50.0	16.7	33.3
13	79.1675	50.0	16.7	33.3
14	91.6675	50.0	16.7	33.3
15	79.1675	50.0	16.7	33.3
16	70.8325	50.0	16.7	33.3
17	75.0000	50.0	16.7	33.3
18	85.4175	50.0	16.7	33.3
1	81.2500	100.0	16.7	33.3
2	52.0825	100.0	16.7	33.3
3	29.1675	100.0	16.7	33.3
4	54.1675	100.0	16.7	33.3
5	62.5000	100.0	16.7	33.3
6	75.0000	100.0	16.7	33.3
7	77.0825	100.0	16.7	33.3
8	93.7500	100.0	16.7	33.3
9	79.1675	100.0	16.7	33.3

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
10	72.9175	100.0	16.7	33.3
11	85.4175	100.0	16.7	33.3
12	85.4175	100.0	16.7	33.3
13	70.8325	100.0	16.7	33.3
14	79.1675	100.0	16.7	33.3
15	72.9175	100.0	16.7	33.3
16	66.6675	100.0	16.7	33.3
17	72.9175	100.0	16.7	33.3
18	75.0000	100.0	16.7	33.3
1	64.5825	16.7	50.0	33.3
2	45.8325	16.7	50.0	33.3
3	35.4175	16.7	50.0	33.3
4	37.5000	16.7	50.0	33.3
5	56.2500	16.7	50.0	33.3
6	62.5000	16.7	50.0	33.3
7	72.9175	16.7	50.0	33.3
8	62.5000	16.7	50.0	33.3
9	66.6675	16.7	50.0	33.3
10	72.9175	16.7	50.0	33.3
11	72.9175	16.7	50.0	33.3
12	72.9175	16.7	50.0	33.3
13	77.0825	16.7	50.0	33.3
14	77.0825	16.7	50.0	33.3
15	81.2500	16.7	50.0	33.3
16	79.1675	16.7	50.0	33.3
17	81.2500	16.7	50.0	33.3
18	83.3325	16.7	50.0	33.3
1	68.7500	50.0	50.0	33.3
2	56.2500	50.0	50.0	33.3
3	27.0825	50.0	50.0	33.3
4	45.8325	50.0	50.0	33.3
5	81.2500	50.0	50.0	33.3
6	79.1675	50.0	50.0	33.3
7	77.0825	50.0	50.0	33.3
8	66.6675	50.0	50.0	33.3
9	60.4175	50.0	50.0	33.3
10	60.4175	50.0	50.0	33.3
11	75.0000	50.0	50.0	33.3
12	87.5000	50.0	50.0	33.3
13	60.4175	50.0	50.0	33.3
14	85.4175	50.0	50.0	33.3
15	85.4175	50.0	50.0	33.3
16	77.0825	50.0	50.0	33.3
17	70.8325	50.0	50.0	33.3
18	62.5000	50.0	50.0	33.3
1	68.7500	100.0	50.0	33.3
2	56.2500	100.0	50.0	33.3
3	41.6675	100.0	50.0	33.3
4	47.9175	100.0	50.0	33.3
5	50.0000	100.0	50.0	33.3
6	79.1675	100.0	50.0	33.3
7	43.7500	100.0	50.0	33.3
8	85.4175	100.0	50.0	33.3
9	39.5825	100.0	50.0	33.3

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
10	60.4175	100.0	50.0	33.3
11	79.1675	100.0	50.0	33.3
12	83.3325	100.0	50.0	33.3
13	27.0825	100.0	50.0	33.3
14	72.9175	100.0	50.0	33.3
15	85.4175	100.0	50.0	33.3
16	72.9175	100.0	50.0	33.3
17	64.5825	100.0	50.0	33.3
18	87.5000	100.0	50.0	33.3
1	37.5000	16.7	100.0	33.3
2	16.6675	16.7	100.0	33.3
3	27.0825	16.7	100.0	33.3
4	41.6675	16.7	100.0	33.3
5	35.4175	16.7	100.0	33.3
6	45.8325	16.7	100.0	33.3
7	50.0000	16.7	100.0	33.3
8	27.0825	16.7	100.0	33.3
9	66.6675	16.7	100.0	33.3
10	35.4175	16.7	100.0	33.3
11	70.8325	16.7	100.0	33.3
12	75.0000	16.7	100.0	33.3
13	50.0000	16.7	100.0	33.3
14	27.0825	16.7	100.0	33.3
15	83.3325	16.7	100.0	33.3
16	52.0825	16.7	100.0	33.3
17	47.9175	16.7	100.0	33.3
18	50.0000	16.7	100.0	33.3
1	45.8325	50.0	100.0	33.3
2	35.4175	50.0	100.0	33.3
3	31.2500	50.0	100.0	33.3
4	37.5000	50.0	100.0	33.3
5	29.5450	50.0	100.0	33.3
6	56.2500	50.0	100.0	33.3
7	43.7500	50.0	100.0	33.3
8	35.4175	50.0	100.0	33.3
9	43.7500	50.0	100.0	33.3
10	18.7500	50.0	100.0	33.3
11	70.8325	50.0	100.0	33.3
12	77.0825	50.0	100.0	33.3
13	41.6675	50.0	100.0	33.3
14	79.1675	50.0	100.0	33.3
15	79.1675	50.0	100.0	33.3
16	58.3325	50.0	100.0	33.3
17	45.8325	50.0	100.0	33.3
18	50.8325	50.0	100.0	33.3
1	60.4175	100.0	100.0	33.3
2	50.0000	100.0	100.0	33.3
3	14.5825	100.0	100.0	33.3
4	35.4175	100.0	100.0	33.3
5	41.6675	100.0	100.0	33.3
6	33.3325	100.0	100.0	33.3
7	22.9175	100.0	100.0	33.3
8	45.8325	100.0	100.0	33.3
9	29.1675	100.0	100.0	33.3

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
10	41.6675	100.0	100.0	33.3
11	52.0825	100.0	100.0	33.3
12	70.8325	100.0	100.0	33.3
13	50.0000	100.0	100.0	33.3
14	68.7500	100.0	100.0	33.3
15	64.5825	100.0	100.0	33.3
16	18.7500	100.0	100.0	33.3
17	50.0000	100.0	100.0	33.3
18	89.5825	100.0	100.0	33.3
19	22.9175	16.7	16.7	50.0
20	56.2500	16.7	16.7	50.0
21	62.5000	16.7	16.7	50.0
22	79.1675	16.7	16.7	50.0
23	41.6675	16.7	16.7	50.0
24	72.9175	16.7	16.7	50.0
25	50.0000	16.7	16.7	50.0
26	81.2500	16.7	16.7	50.0
27	72.9175	16.7	16.7	50.0
28	87.5000	16.7	16.7	50.0
29	33.3325	16.7	16.7	50.0
30	47.9175	16.7	16.7	50.0
31	85.4175	16.7	16.7	50.0
32	37.5000	16.7	16.7	50.0
33	77.0825	16.7	16.7	50.0
34	79.1675	16.7	16.7	50.0
35	75.0000	16.7	16.7	50.0
36	79.1675	16.7	16.7	50.0
19	29.1675	50.0	16.7	50.0
20	56.2500	50.0	16.7	50.0
21	52.0825	50.0	16.7	50.0
22	66.6675	50.0	16.7	50.0
23	66.6675	50.0	16.7	50.0
24	68.7500	50.0	16.7	50.0
25	64.5825	50.0	16.7	50.0
26	68.7500	50.0	16.7	50.0
27	85.4175	50.0	16.7	50.0
28	62.5000	50.0	16.7	50.0
29	68.7500	50.0	16.7	50.0
30	45.8325	50.0	16.7	50.0
31	75.0000	50.0	16.7	50.0
32	27.0825	50.0	16.7	50.0
33	62.5000	50.0	16.7	50.0
34	72.9175	50.0	16.7	50.0
35	58.3325	50.0	16.7	50.0
36	54.1675	50.0	16.7	50.0
19	12.5000	100.0	16.7	50.0
20	52.0825	100.0	16.7	50.0
21	58.3325	100.0	16.7	50.0
22	79.1675	100.0	16.7	50.0
23	56.2500	100.0	16.7	50.0
24	58.3325	100.0	16.7	50.0
25	43.7500	100.0	16.7	50.0
26	75.0000	100.0	16.7	50.0

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
27	68.7500	100.0	16.7	50.0
28	56.2500	100.0	16.7	50.0
29	58.3325	100.0	16.7	50.0
30	37.5000	100.0	16.7	50.0
31	77.0825	100.0	16.7	50.0
32	22.9175	100.0	16.7	50.0
33	62.5000	100.0	16.7	50.0
34	70.8325	100.0	16.7	50.0
35	41.6675	100.0	16.7	50.0
36	60.4175	100.0	16.7	50.0
19	20.8325	16.7	50.0	50.0
20	47.9175	16.7	50.0	50.0
21	64.5825	16.7	50.0	50.0
22	37.5000	16.7	50.0	50.0
23	43.7500	16.7	50.0	50.0
24	45.8325	16.7	50.0	50.0
25	41.6675	16.7	50.0	50.0
26	64.5825	16.7	50.0	50.0
27	60.4175	16.7	50.0	50.0
28	47.9175	16.7	50.0	50.0
29	37.5000	16.7	50.0	50.0
30	18.7500	16.7	50.0	50.0
31	70.8325	16.7	50.0	50.0
32	16.6675	16.7	50.0	50.0
33	64.5825	16.7	50.0	50.0
34	68.7500	16.7	50.0	50.0
35	50.0000	16.7	50.0	50.0
36	75.0000	16.7	50.0	50.0
19	27.0825	50.0	50.0	50.0
20	70.8325	50.0	50.0	50.0
21	39.5825	50.0	50.0	50.0
22	79.1675	50.0	50.0	50.0
23	60.4175	50.0	50.0	50.0
24	60.4175	50.0	50.0	50.0
25	56.2500	50.0	50.0	50.0
26	75.0000	50.0	50.0	50.0
27	62.5000	50.0	50.0	50.0
28	72.9175	50.0	50.0	50.0
29	43.7500	50.0	50.0	50.0
30	20.8325	50.0	50.0	50.0
31	68.7500	50.0	50.0	50.0
32	29.1675	50.0	50.0	50.0
33	66.6675	50.0	50.0	50.0
34	64.5825	50.0	50.0	50.0
35	50.0000	50.0	50.0	50.0
36	29.1675	50.0	50.0	50.0
19	14.5825	100.0	50.0	50.0
20	52.0825	100.0	50.0	50.0
21	47.9175	100.0	50.0	50.0
22	47.9175	100.0	50.0	50.0
23	47.9175	100.0	50.0	50.0
24	33.3325	100.0	50.0	50.0
25	45.8325	100.0	50.0	50.0
26	64.5825	100.0	50.0	50.0

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
27	35.4175	100.0	50.0	50.0
28	62.5000	100.0	50.0	50.0
29	39.5825	100.0	50.0	50.0
30	16.6675	100.0	50.0	50.0
31	29.1675	100.0	50.0	50.0
32	14.5825	100.0	50.0	50.0
33	75.0000	100.0	50.0	50.0
34	43.7500	100.0	50.0	50.0
35	54.1675	100.0	50.0	50.0
36	35.4175	100.0	50.0	50.0
19	10.4175	16.7	100.0	50.0
20	20.8325	16.7	100.0	50.0
21	41.6675	16.7	100.0	50.0
22	60.4175	16.7	100.0	50.0
23	43.7500	16.7	100.0	50.0
24	22.9175	16.7	100.0	50.0
25	35.4175	16.7	100.0	50.0
26	52.0825	16.7	100.0	50.0
27	64.5825	16.7	100.0	50.0
28	50.0000	16.7	100.0	50.0
29	27.0825	16.7	100.0	50.0
30	12.5000	16.7	100.0	50.0
31	58.3325	16.7	100.0	50.0
32	6.2500	16.7	100.0	50.0
33	79.1675	16.7	100.0	50.0
34	35.4175	16.7	100.0	50.0
35	35.4175	16.7	100.0	50.0
36	70.8325	16.7	100.0	50.0
19	20.8325	50.0	100.0	50.0
20	50.0000	50.0	100.0	50.0
21	39.5825	50.0	100.0	50.0
22	56.2500	50.0	100.0	50.0
23	37.5000	50.0	100.0	50.0
24	41.6675	50.0	100.0	50.0
25	27.0825	50.0	100.0	50.0
26	45.8325	50.0	100.0	50.0
27	20.8325	50.0	100.0	50.0
28	16.6675	50.0	100.0	50.0
29	31.2500	50.0	100.0	50.0
30	16.6675	50.0	100.0	50.0
31	54.1675	50.0	100.0	50.0
32	22.9175	50.0	100.0	50.0
33	66.6675	50.0	100.0	50.0
34	50.0000	50.0	100.0	50.0
35	47.9175	50.0	100.0	50.0
36	45.8325	50.0	100.0	50.0
19	10.4175	100.0	100.0	50.0
20	27.0825	100.0	100.0	50.0
21	29.1675	100.0	100.0	50.0
22	56.2500	100.0	100.0	50.0
23	39.5825	100.0	100.0	50.0
24	14.5825	100.0	100.0	50.0
25	22.9175	100.0	100.0	50.0
26	27.0825	100.0	100.0	50.0

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
27	20.8325	100.0	100.0	50.0
28	35.4175	100.0	100.0	50.0
29	43.7500	100.0	100.0	50.0
30	6.2500	100.0	100.0	50.0
31	43.7500	100.0	100.0	50.0
32	14.5825	100.0	100.0	50.0
33	52.0825	100.0	100.0	50.0
34	20.8325	100.0	100.0	50.0
35	18.1825	100.0	100.0	50.0
36	35.4175	100.0	100.0	50.0
37	47.9175	16.7	16.7	66.7
38	50.0000	16.7	16.7	66.7
39	29.1675	16.7	16.7	66.7
40	75.0000	16.7	16.7	66.7
41	64.5825	16.7	16.7	66.7
42	54.1675	16.7	16.7	66.7
43	22.9175	16.7	16.7	66.7
44	14.5825	16.7	16.7	66.7
45	70.8325	16.7	16.7	66.7
46	70.8325	16.7	16.7	66.7
47	12.5000	16.7	16.7	66.7
48	62.5000	16.7	16.7	66.7
49	58.3325	16.7	16.7	66.7
50	41.6675	16.7	16.7	66.7
51	58.3325	16.7	16.7	66.7
52	62.5000	16.7	16.7	66.7
53	64.5825	16.7	16.7	66.7
54	47.9175	16.7	16.7	66.7
37	56.2500	50.0	16.7	66.7
38	47.9175	50.0	16.7	66.7
39	43.7500	50.0	16.7	66.7
40	72.9175	50.0	16.7	66.7
41	50.0000	50.0	16.7	66.7
42	35.4175	50.0	16.7	66.7
43	45.8325	50.0	16.7	66.7
44	4.1675	50.0	16.7	66.7
45	77.0825	50.0	16.7	66.7
46	62.5000	50.0	16.7	66.7
47	60.4175	50.0	16.7	66.7
48	87.5000	50.0	16.7	66.7
49	54.1675	50.0	16.7	66.7
50	41.6675	50.0	16.7	66.7
51	52.0825	50.0	16.7	66.7
52	75.0000	50.0	16.7	66.7
53	64.5825	50.0	16.7	66.7
54	43.7500	50.0	16.7	66.7
37	33.3325	100.0	16.7	66.7
38	41.6675	100.0	16.7	66.7
39	33.3325	100.0	16.7	66.7
40	66.6675	100.0	16.7	66.7
41	68.7500	100.0	16.7	66.7
42	33.3325	100.0	16.7	66.7
43	35.4175	100.0	16.7	66.7

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
44	8.3325	100.0	16.7	66.7
45	77.0825	100.0	16.7	66.7
46	64.5825	100.0	16.7	66.7
47	31.2500	100.0	16.7	66.7
48	68.7500	100.0	16.7	66.7
49	56.2500	100.0	16.7	66.7
50	37.5000	100.0	16.7	66.7
51	60.4175	100.0	16.7	66.7
52	68.7500	100.0	16.7	66.7
53	33.3325	100.0	16.7	66.7
54	58.3325	100.0	16.7	66.7
37	29.1675	16.7	50.0	66.7
38	29.1675	16.7	50.0	66.7
39	33.3325	16.7	50.0	66.7
40	43.7500	16.7	50.0	66.7
41	58.3325	16.7	50.0	66.7
42	18.7500	16.7	50.0	66.7
43	33.3325	16.7	50.0	66.7
44	16.6675	16.7	50.0	66.7
45	56.2500	16.7	50.0	66.7
46	43.7500	16.7	50.0	66.7
47	31.2500	16.7	50.0	66.7
48	22.9175	16.7	50.0	66.7
49	58.3325	16.7	50.0	66.7
50	47.9175	16.7	50.0	66.7
51	50.0000	16.7	50.0	66.7
52	31.2500	16.7	50.0	66.7
53	60.4175	16.7	50.0	66.7
54	33.3325	16.7	50.0	66.7
37	35.4175	50.0	50.0	66.7
38	45.8325	50.0	50.0	66.7
39	29.1675	50.0	50.0	66.7
40	64.5825	50.0	50.0	66.7
41	72.9175	50.0	50.0	66.7
42	12.5000	50.0	50.0	66.7
43	27.0825	50.0	50.0	66.7
44	6.2500	50.0	50.0	66.7
45	66.6675	50.0	50.0	66.7
46	56.2500	50.0	50.0	66.7
47	25.0000	50.0	50.0	66.7
48	70.8325	50.0	50.0	66.7
49	66.6675	50.0	50.0	66.7
50	29.1675	50.0	50.0	66.7
51	37.5000	50.0	50.0	66.7
52	27.0825	50.0	50.0	66.7
53	62.5000	50.0	50.0	66.7
54	22.9175	50.0	50.0	66.7
37	25.0000	100.0	50.0	66.7
38	56.2500	100.0	50.0	66.7
39	29.1675	100.0	50.0	66.7
40	56.2500	100.0	50.0	66.7
41	47.9175	100.0	50.0	66.7
42	35.4175	100.0	50.0	66.7
43	43.7500	100.0	50.0	66.7

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
44	6.2500	100.0	50.0	66.7
45	45.8325	100.0	50.0	66.7
46	25.0000	100.0	50.0	66.7
47	31.2500	100.0	50.0	66.7
48	50.0000	100.0	50.0	66.7
49	37.5000	100.0	50.0	66.7
50	20.8325	100.0	50.0	66.7
51	45.8325	100.0	50.0	66.7
52	31.2500	100.0	50.0	66.7
53	45.8325	100.0	50.0	66.7
54	39.5825	100.0	50.0	66.7
37	20.8325	16.7	100.0	66.7
38	27.0825	16.7	100.0	66.7
39	12.5000	16.7	100.0	66.7
40	50.0000	16.7	100.0	66.7
41	54.1675	16.7	100.0	66.7
42	8.3325	16.7	100.0	66.7
43	31.8175	16.7	100.0	66.7
44	2.0825	16.7	100.0	66.7
45	81.2500	16.7	100.0	66.7
46	37.5000	16.7	100.0	66.7
47	37.5000	16.7	100.0	66.7
48	47.9175	16.7	100.0	66.7
49	22.9175	16.7	100.0	66.7
50	16.6675	16.7	100.0	66.7
51	60.4175	16.7	100.0	66.7
52	14.5825	16.7	100.0	66.7
53	43.7500	16.7	100.0	66.7
54	45.8325	16.7	100.0	66.7
37	25.0000	50.0	100.0	66.7
38	33.3325	50.0	100.0	66.7
39	29.1675	50.0	100.0	66.7
40	47.9175	50.0	100.0	66.7
41	50.0000	50.0	100.0	66.7
42	16.6675	50.0	100.0	66.7
43	0.0000	50.0	100.0	66.7
44	8.3325	50.0	100.0	66.7
45	68.7500	50.0	100.0	66.7
46	12.5000	50.0	100.0	66.7
47	41.6675	50.0	100.0	66.7
48	35.4175	50.0	100.0	66.7
49	18.7500	50.0	100.0	66.7
50	16.6675	50.0	100.0	66.7
51	47.9175	50.0	100.0	66.7
52	16.6675	50.0	100.0	66.7
53	22.9175	50.0	100.0	66.7
54	33.3325	50.0	100.0	66.7
37	18.7500	100.0	100.0	66.7
38	45.8325	100.0	100.0	66.7
39	18.7500	100.0	100.0	66.7
40	60.4175	100.0	100.0	66.7
41	58.3325	100.0	100.0	66.7
42	18.7500	100.0	100.0	66.7
43	4.1675	100.0	100.0	66.7

A.5

Experiment 1:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
44	2.0825	100.0	100.0	66.7
45	58.3325	100.0	100.0	66.7
46	16.6675	100.0	100.0	66.7
47	33.3325	100.0	100.0	66.7
48	29.1675	100.0	100.0	66.7
49	12.5000	100.0	100.0	66.7
50	16.6675	100.0	100.0	66.7
51	54.1675	100.0	100.0	66.7
52	18.7500	100.0	100.0	66.7
53	39.5825	100.0	100.0	66.7
54	43.7500	100.0	100.0	66.7

Experiment 2:

Subject	% Correct	Sd2 (ms)	Mask
1	83.650	50	Superposition
2	87.500	50	Superposition
3	85.575	50	Superposition
4	84.625	50	Superposition
5	72.125	50	Superposition
6	88.450	50	Superposition
7	63.450	50	Superposition
8	98.075	50	Superposition
1	89.425	100	Superposition
2	83.650	100	Superposition
3	80.775	100	Superposition
4	72.125	100	Superposition
5	54.800	100	Superposition
6	92.300	100	Superposition
7	87.500	100	Superposition
8	95.200	100	Superposition
1	75.000	50	Bar
2	77.875	50	Bar
3	75.950	50	Bar
4	69.225	50	Bar
5	27.875	50	Bar
6	87.500	50	Bar
7	76.000	50	Bar
8	75.950	50	Bar
1	73.075	100	Bar
2	78.850	100	Bar
3	50.950	100	Bar
4	69.225	100	Bar
5	25.000	100	Bar
6	85.575	100	Bar
7	64.425	100	Bar
8	82.700	100	Bar

A.5

Experiment 3:

Subject	Sd2 (ms)	% Correct	% 1st Error
LMG	50	99	100.0
LMG	100	76	87.5
LMG	150	81	94.7
LMG	200	32	75.0
DFS	50	90	60.0
DFS	100	87	92.3
DFS	150	67	90.9
DFS	200	55	93.3
RAV	50	79	52.4
RAV	100	71	75.9
RAV	150	61	82.1
RAV	200	26	85.1
CLD	50	90	80.0
CLD	100	85	60.0
CLD	150	39	85.2
CLD	200	21	83.5
PRT	50	89	36.4
PRT	100	80	80.0
PRT	150	55	80.0
PRT	200	28	97.2

Experiment 4:

E.set conditions:-

Subject	% Score	Intensified duration (ms)
SYB	76	10
SYB	69	30
SYB	63	50
DFS	78	10
DFS	52	30
DFS	58	50
LMG	98	10
LMG	88	30
LMG	68	50
PAR	55	10
PAR	62	30
PAR	48	50

Control 1 conditions:-

Subject	% Score	S2 brightness
SYB	30	Low
SYB	18	Medium
SYB	20	High
DFS	46	Low
DFS	38	Medium
DFS	24	High
LMG	48	Low
LMG	56	Medium
LMG	29	High
PAR	23	Low
PAR	31	Medium

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Experiment 4:

Control 1 conditions:-

Subject	% Score	S2 brightness
PAR	28	High

Experiment 4:

Control 2 conditions:-

Initial	% Score	Sd2 (ms)
SYB	85	10
SYB	84	30
SYB	81	50
DFS	98	10
DFS	97	30
DFS	97	50
LMG	98	10
LMG	99	30
LMG	95	50
PAR	77	10
PAR	78	30
PAR	81	50

Experiment 5:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
LMG	76	10	10	55
DFS	31	10	10	55
SYB	56	10	10	55
ABI	60	10	10	55
TC	88	10	10	55
HB	88	10	10	55
LMG	85	30	10	35
DFS	69	30	10	35
SYB	64	30	10	35
ABI	75	30	10	35
TC	95	30	10	35
HB	90	30	10	35
LMG	98	50	10	15
DFS	99	50	10	15
SYB	74	50	10	15
ABI	76	50	10	15
TC	98	50	10	15
HB	96	50	10	15
LMG	92	10	30	35
DFS	57	10	30	35
SYB	59	10	30	35
ABI	73	10	30	35
TC	99	10	30	35
HB	87	10	30	35

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Experiment 5:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
LMG	97	10	50	15
DFS	89	10	50	15
SYB	77	10	50	15
ABI	73	10	50	15
TC	96	10	50	15
HB	87	10	50	15

Experiment 5:

Subject	% Score	Sd1 (ms)	Sd2 (ms)	ISI (ms)
LMG	55	10	10	75
DFS	11	10	10	75
SYB	19	10	10	75
ABI	45	10	10	75
TC	57	10	10	75
HB	65	10	10	75
LMG	67	30	10	55
DFS	18	30	10	55
SYB	23	30	10	55
ABI	50	30	10	55
TC	85	30	10	55
HB	85	30	10	55
LMG	93	50	10	35
DFS	54	50	10	35
SYB	53	50	10	35
ABI	78	50	10	35
TC	83	50	10	35
HB	83	50	10	35
LMG	63	10	30	55
DFS	26	10	30	55
SYB	30	10	30	55
ABI	41	10	30	55
TC	76	10	30	55
HB	76	10	30	55
LMG	81	10	50	35
DFS	35	10	50	35
SYB	42	10	50	35
ABI	61	10	50	35
TC	90	10	50	35
HB	84	10	50	35

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Experiment 6:

Experimental letter ID and control data:-

Subject	Experimental % Score	Control % Score	Sd2 (ms)
DRL	31	20	1
DRL	78	60	50
DRL	92	50	100
DFS	64	25	1
DFS	88	30	10
DFS	92	35	30
DFS	86	35	50
DFS	85	35	100
RAV	56	40	1
RAV	68	40	10
RAV	82	30	30
RAV	76	30	50
RAV	88	20	100
IRM	58	30	1
IRM	83	15	50
IRM	93	35	100
TFP	71	35	1
TFP	97	30	50
TFP	99	40	100
SDA	40	15	1
SDA	83	25	10
SDA	93	50	30
SDA	86	45	50
SDA	82	15	100

Experiment 6:

Missing dot conditions:-

Subject	% Score	% 1st Error	Sd2 (ms)
DRL	91	55.56	1
DRL	79	80.95	50
DRL	60	90.00	100
DFS	92	75.00	1
DFS	89	63.64	10
DFS	89	63.64	30
DFS	80	90.00	50
DFS	40	95.00	100
RAV	70	36.67	1
RAV	80	35.00	10
RAV	61	61.54	30
RAV	46	61.11	50
RAV	23	51.95	100
IRM	97	33.33	1
IRM	68	90.63	50
IRM	29	85.92	100
TFP	100	0.00	1
TFP	82	88.89	50
TFP	49	80.39	100
SDA	97	100.00	1
SDA	96	25.00	10

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Missing dot conditions:-

Subject	% Score	% 1st Error	Sd2 (ms)
SDA	83	58.82	30
SDA	80	75.00	50
SDA	39	86.89	100

Experiment 6:

Missing dot data by 1st field letter:-

Initial	Letter	Score	Sd2
TFP	A	0	1
DRL	A	3	1
IRM	A	0	1
DFS	A	2	1
SDA	A	1	1
RAV	A	2	1
TFP	C	0	1
DRL	C	1	1
IRM	C	0	1
DFS	C	0	1
SDA	C	0	1
RAV	C	6	1
TFP	E	0	1
DRL	E	1	1
IRM	E	0	1
DFS	E	0	1
SDA	E	0	1
RAV	E	2	1
TFP	H	0	1
DRL	H	1	1
IRM	H	1	1
DFS	H	0	1
SDA	H	1	1
RAV	H	2	1
TFP	M	0	1
DRL	M	1	1
IRM	M	0	1
DFS	M	0	1
SDA	M	0	1
RAV	M	3	1
TFP	P	0	1
DRL	P	1	1
IRM	P	0	1
DFS	P	1	1
SDA	P	1	1
RAV	P	4	1
TFP	S	0	1
DRL	S	0	1
IRM	S	1	1
DFS	S	1	1
SDA	S	0	1
RAV	S	2	1
TFP	U	0	1
DRL	U	0	1
IRM	U	0	1

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Missing dot data by 1st field letter:-

Initial	Letter	Score	Sd2
DFS	U	1	1
SDA	U	0	1
RAV	U	4	1
TFP	W	0	1
DRL	W	0	1
IRM	W	1	1
DFS	W	0	1
SDA	W	0	1
RAV	W	2	1
TFP	Z	0	1
DRL	Z	1	1
IRM	Z	0	1
DFS	Z	3	1
SDA	Z	0	1
RAV	Z	3	1
DFS	A	2	10
SDA	A	1	10
RAV	A	3	10
DFS	C	0	10
SDA	C	0	10
RAV	C	0	10
DFS	E	1	10
SDA	E	0	10
RAV	E	2	10
DFS	H	0	10
SDA	H	1	10
RAV	H	1	10
DFS	M	0	10
SDA	M	0	10
RAV	M	1	10
DFS	P	1	10
SDA	P	1	10
RAV	P	1	10
DFS	S	3	10
SDA	S	0	10
RAV	S	3	10
DFS	U	1	10
SDA	U	0	10
RAV	U	3	10
DFS	W	0	10
SDA	W	1	10
RAV	W	3	10
DFS	Z	3	10
SDA	Z	0	10
RAV	Z	3	10
DFS	A	0	30
SDA	A	2	30
RAV	A	5	30
DFS	C	0	30
SDA	C	0	30
RAV	C	5	30
DFS	E	0	30
SDA	E	0	30
RAV	E	4	30

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Missing dot data by 1st field letter:-

Initial	Letter	Score	Sd2
DFS	H	2	30
SDA	H	2	30
RAV	H	3	30
DFS	M	1	30
SDA	M	1	30
RAV	M	2	30
DFS	P	2	30
SDA	P	4	30
RAV	P	7	30
DFS	S	2	30
SDA	S	3	30
RAV	S	3	30
DFS	U	0	30
SDA	U	1	30
RAV	U	2	30
DFS	W	2	30
SDA	W	2	30
RAV	W	3	30
DFS	Z	2	30
SDA	Z	2	30
RAV	Z	5	30
TFP	A	5	50
DRL	A	5	50
IRM	A	7	50
DFS	A	2	50
SDA	A	2	50
RAV	A	7	50
TFP	C	0	50
DRL	C	0	50
IRM	C	0	50
DFS	C	0	50
SDA	C	1	50
RAV	C	4	50
TFP	E	2	50
DRL	E	0	50
IRM	E	1	50
DFS	E	0	50
SDA	E	4	50
RAV	E	6	50
TFP	H	0	50
DRL	H	2	50
IRM	H	4	50
DFS	H	1	50
SDA	H	2	50
RAV	H	5	50
TFP	M	2	50
DRL	M	1	50
IRM	M	3	50
DFS	M	3	50
SDA	M	2	50
RAV	M	5	50
TFP	P	3	50
DRL	P	4	50
IRM	P	4	50

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Missing dot data by 1st field letter:-

Initial	Letter	Score	Sd2
DFS	P	2	50
SDA	P	4	50
RAV	P	7	50
TFP	S	5	50
DRL	S	1	50
IRM	S	5	50
DFS	S	2	50
SDA	S	3	50
RAV	S	7	50
TFP	U	0	50
DRL	U	1	50
IRM	U	3	50
DFS	U	1	50
SDA	U	1	50
RAV	U	7	50
TFP	W	0	50
DRL	W	3	50
IRM	W	3	50
DFS	W	4	50
SDA	W	1	50
RAV	W	3	50
TFP	Z	1	50
DRL	Z	4	50
IRM	Z	2	50
DFS	Z	5	50
SDA	Z	0	50
RAV	Z	3	50
TFP	A	8	100
DRL	A	5	100
IRM	A	9	100
DFS	A	8	100
SDA	A	8	100
RAV	A	9	100
TFP	C	4	100
DRL	C	0	100
IRM	C	3	100
DFS	C	3	100
SDA	C	5	100
RAV	C	7	100
TFP	E	5	100
DRL	E	3	100
IRM	E	4	100
DFS	E	9	100
SDA	E	7	100
RAV	E	6	100
TFP	H	7	100
DRL	H	4	100
IRM	H	8	100
DFS	H	3	100
SDA	H	6	100
RAV	H	9	100
TFP	M	5	100
DRL	M	4	100
IRM	M	9	100

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Missing dot data by 1st field letter:-

Initial	Letter	Score	Sd2
DFS	M	7	100
SDA	M	4	100
RAV	M	8	100
TFP	P	2	100
DRL	P	6	100
IRM	P	10	100
DFS	P	7	100
SDA	P	8	100
RAV	P	8	100
TFP	S	9	100
DRL	S	7	100
IRM	S	10	100
DFS	S	7	100
SDA	S	10	100
RAV	S	10	100
TFP	U	3	100
DRL	U	0	100
IRM	U	6	100
DFS	U	4	100
SDA	U	2	100
RAV	U	4	100
TFP	W	6	100
DRL	W	7	100
IRM	W	6	100
DFS	W	5	100
SDA	W	6	100
RAV	W	9	100
TFP	Z	2	100
DRL	Z	4	100
IRM	Z	6	100
DFS	Z	7	100
SDA	Z	5	100
RAV	Z	7	100

Experiment 8 (scores are given as percentages):

Single letter report :-

Sub.	Correct	Trans.	Intr.	Sd1 ms	ISI ms	Sd2 ms
1	100	0	0	33	17	33
2	75	25	0	33	17	33
3	90	10	0	33	17	33
4	85	10	5	33	17	33
5	80	20	0	33	17	33
6	95	5	0	33	17	33
7	100	0	0	33	17	33
8	95	5	0	33	17	33
1	95	5	0	100	17	33
2	40	50	10	100	17	33
3	70	25	5	100	17	33
4	75	20	5	100	17	33
5	55	40	5	100	17	33
6	90	5	5	100	17	33

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Single letter report:-

Sub.	Correct	Trans.	Intr.	Sd1 ms	ISI ms	Sd2 ms
7	85	10	5	100	17	33
8	75	20	5	100	17	33
1	85	10	5	33	100	33
2	40	60	0	33	100	33
3	80	15	5	33	100	33
4	60	30	10	33	100	33
5	45	40	15	33	100	33
6	80	20	0	33	100	33
7	45	45	10	33	100	33
8	60	30	10	33	100	33
1	100	0	0	33	17	100
2	65	25	10	33	17	100
3	75	20	5	33	17	100
4	65	25	10	33	17	100
5	60	35	5	33	17	100
6	90	0	10	33	17	100
7	90	10	0	33	17	100
8	75	20	5	33	17	100
1	55	40	5	100	100	33
2	45	30	25	100	100	33
3	65	30	5	100	100	33
4	55	30	15	100	100	33
5	55	40	5	100	100	33
6	65	20	15	100	100	33
7	50	50	0	100	100	33
8	55	30	15	100	100	33
1	75	25	0	33	100	100
2	15	75	10	33	100	100
3	45	50	5	33	100	100
4	40	40	20	33	100	100
5	65	30	5	33	100	100
6	65	25	10	33	100	100
7	35	40	25	33	100	100
8	40	55	5	33	100	100
1	85	10	5	100	17	100
2	40	45	15	100	17	100
3	70	20	10	100	17	100
4	55	30	15	100	17	100
5	60	35	5	100	17	100
6	85	10	5	100	17	100
7	75	15	10	100	17	100
8	70	15	15	100	17	100
1	75	25	0	100	100	100
2	40	55	5	100	100	100
3	50	25	25	100	100	100
4	35	65	0	100	100	100
5	35	55	10	100	100	100
6	60	25	15	100	100	100

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Single letter report:-

Sub.	Correct	Trans.	Intr.	Sd1 ms	ISI ms	Sd2 ms
7	40	50	10	100	100	100
8	45	45	10	100	100	100

Experiment 8.

Full row report. Data for indirect targets:-

Sub.	Score	Trans.	Intr.	Sd1 ms	ISI ms	Sd2 ms
1	68.75	18.75	12.50	33	17	33
2	43.75	32.50	23.75	33	17	33
3	71.25	15.00	13.75	33	17	33
4	62.50	25.00	12.50	33	17	33
5	87.50	5.00	7.50	33	17	33
6	73.75	17.50	8.75	33	17	33
7	56.25	28.75	15.00	33	17	33
8	66.25	17.50	16.25	33	17	33
1	67.50	26.25	6.25	100	17	33
2	47.50	37.50	15.00	100	17	33
3	68.75	16.25	15.00	100	17	33
4	66.25	20.00	13.75	100	17	33
5	73.75	15.00	11.25	100	17	33
6	71.25	17.50	11.25	100	17	33
7	65.00	22.50	12.50	100	17	33
8	62.50	21.25	16.25	100	17	33
1	62.50	25.00	12.50	33	100	33
2	30.00	38.75	31.25	33	100	33
3	65.00	15.00	20.00	33	100	33
4	63.75	26.25	10.00	33	100	33
5	56.25	33.75	10.00	33	100	33
6	66.25	26.25	7.50	33	100	33
7	55.00	26.25	18.75	33	100	33
8	43.75	41.25	15.00	33	100	33
1	68.75	22.50	8.75	33	17	100
2	42.50	32.50	25.00	33	17	100
3	76.25	11.25	12.50	33	17	100
4	53.75	27.50	18.75	33	17	100
5	60.00	23.75	16.25	33	17	100
6	66.25	22.50	11.25	33	17	100
7	56.25	26.25	17.50	33	17	100
8	60.00	17.50	22.50	33	17	100
1	51.25	28.75	20.00	100	100	33
2	42.50	31.25	26.25	100	100	33
3	65.00	23.75	11.25	100	100	33
4	52.50	38.75	8.75	100	100	33
5	61.25	26.25	12.50	100	100	33
6	62.50	30.00	7.50	100	100	33
7	47.50	36.25	16.25	100	100	33
8	46.25	33.75	20.00	100	100	33
1	42.50	38.75	18.75	33	100	100

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Full row report. Data for indirect targets:-

Sub.	Score	Trans.	Intr.	Sd1 ms	ISI ms	Sd2 ms
2	38.75	38.75	22.50	33	100	100
3	65.00	20.00	15.00	33	100	100
4	45.00	32.50	22.50	33	100	100
5	58.75	25.00	16.25	33	100	100
6	70.00	23.75	6.25	33	100	100
7	43.75	37.50	18.75	33	100	100
8	42.50	41.25	16.25	33	100	100
1	51.25	33.75	15.00	100	17	100
2	47.50	36.25	16.25	100	17	100
3	73.75	20.00	6.25	100	17	100
4	60.00	26.25	13.75	100	17	100
5	73.75	15.00	11.25	100	17	100
6	78.75	12.50	8.75	100	17	100
7	55.00	21.25	23.75	100	17	100
8	56.25	23.75	20.00	100	17	100
1	50.00	37.50	12.50	100	100	100
2	33.75	46.25	20.00	100	100	100
3	58.75	18.75	22.50	100	100	100
4	48.75	35.00	16.25	100	100	100
5	66.25	20.00	13.75	100	100	100
6	63.75	31.25	5.00	100	100	100
7	43.75	28.75	27.50	100	100	100
8	50.00	30.00	20.00	100	100	100

A.5

Experiment 8:

Full row report. Data for direct targets:-

Sub.	Score	Trans.	Intr.	Sd1 ms	ISI ms	Sd2 ms
1	75	25	0	33	17	33
2	70	15	15	33	17	33
3	85	10	5	33	17	33
4	70	15	15	33	17	33
5	95	5	0	33	17	33
6	95	0	5	33	17	33
7	70	30	0	33	17	33
8	65	10	25	33	17	33
1	80	15	5	100	17	33
2	45	25	30	100	17	33
3	70	15	15	100	17	33
4	65	15	20	100	17	33
5	75	25	0	100	17	33
6	65	15	20	100	17	33
7	65	20	15	100	17	33
8	60	20	20	100	17	33
1	80	10	10	33	100	33
2	15	55	30	33	100	33
3	70	25	5	33	100	33
4	45	35	20	33	100	33
5	45	30	25	33	100	33
6	70	25	5	33	100	33
7	40	35	25	33	100	33
8	55	35	10	33	100	33
1	75	25	0	33	17	100
2	45	25	30	33	17	100
3	80	10	10	33	17	100
4	60	30	10	33	17	100
5	50	40	10	33	17	100
6	75	20	5	33	17	100
7	70	15	15	33	17	100
8	65	10	25	33	17	100
1	55	30	15	100	100	33
2	40	35	25	100	100	33
3	75	15	10	100	100	33
4	25	50	25	100	100	33
5	65	15	20	100	100	33
6	70	25	5	100	100	33
7	55	25	20	100	100	33
8	50	40	10	100	100	33
1	40	35	25	33	100	100
2	40	45	15	33	100	100
3	55	40	5	33	100	100
4	35	50	15	33	100	100
5	50	25	25	33	100	100
6	75	20	5	33	100	100
7	35	10	55	33	100	100

A.5

Full row report. Data for direct targets:-

Sub.	Score	Trans.	Intr.	Sd1 ms	ISI ms	Sd2 ms
8	45	30	25	33	100	100
1	70	15	15	100	17	100
2	55	35	10	100	17	100
3	70	20	10	100	17	100
4	45	45	10	100	17	100
5	60	25	15	100	17	100
6	70	30	0	100	17	100
7	50	40	10	100	17	100
8	50	35	15	100	17	100
1	60	30	10	100	100	100
2	25	60	15	100	100	100
3	75	15	10	100	100	100
4	35	55	10	100	100	100
5	55	5	40	100	100	100
6	55	30	15	100	100	100
7	35	35	30	100	100	100
8	50	30	20	100	100	100

Experiment 8.
Full row report. Numbers of horizontally adjacent (H. Trans.) and vertically adjacent (V. Trans.) transpositions:-

Sub.	H. Trans.	V. Trans.	Sd1 ms	ISI ms	Sd2 ms
1	2	3	33	17	33
2	4	7	33	17	33
3	2	4	33	17	33
4	4	5	33	17	33
5	0	2	33	17	33
6	3	7	33	17	33
7	9	4	33	17	33
8	4	2	33	17	33
1	6	10	100	17	33
2	6	13	100	17	33
3	3	4	100	17	33
4	8	4	100	17	33
5	4	1	100	17	33
6	5	6	100	17	33
7	8	4	100	17	33
8	4	6	100	17	33
1	4	11	33	100	33
2	5	16	33	100	33
3	4	3	33	100	33
4	9	3	33	100	33
5	4	8	33	100	33
6	8	6	33	100	33
7	6	4	33	100	33
8	12	11	33	100	33

A.5

Full row report, H. Trans. & V. Trans:

Sub.	H. Trans.	V. Trans.	Sd1 ms	ISI ms	Sd2 ms
1	3	5	33	17	100
2	7	12	33	17	100
3	1	6	33	17	100
4	10	6	33	17	100
5	7	6	33	17	100
6	8	3	33	17	100
7	5	4	33	17	100
8	5	1	33	17	100
1	8	7	100	100	33
2	6	12	100	100	33
3	4	6	100	100	33
4	13	9	100	100	33
5	1	9	100	100	33
6	6	8	100	100	33
7	7	14	100	100	33
8	6	4	100	100	33
1	8	16	33	100	100
2	5	20	33	100	100
3	5	5	33	100	100
4	7	4	33	100	100
5	6	6	33	100	100
6	2	7	33	100	100
7	3	15	33	100	100
8	6	7	33	100	100
1	6	9	100	17	100
2	4	12	100	17	100
3	4	6	100	17	100
4	8	3	100	17	100
5	3	7	100	17	100
6	0	8	100	17	100
7	5	3	100	17	100
8	3	6	100	17	100
1	11	12	100	100	100
2	7	33	100	100	100
3	5	5	100	100	100
4	8	9	100	100	100
5	2	9	100	100	100
6	3	9	100	100	100
7	4	11	100	100	100
8	9	5	100	100	100

A.5

Pilot 2:
Brightness matching against a 100 ms referent stimulus that was projected at a dot luminance of 0.057 cd/m²:-

Target Duration (ms)	Target dot luminance (cd/m²)				
	LMG	DFS	RAV	CLD	PRT
1	3.861	3.861	2.907	4.842	5.391
10	0.302	0.353	0.265	0.382	0.429
20	0.192	0.198	0.192	0.198	0.198
30	0.162	0.175	0.162	0.167	0.167
40	0.139	0.154	0.139	0.145	0.154
50	0.123	0.130	0.123	0.123	0.130
60	0.105	0.114	0.105	0.105	0.114
70	0.091	0.097	0.091	0.091	0.105
80	0.074	0.082	0.082	0.074	0.091
90	0.057	0.074	0.066	0.066	0.082

Pilot 3:
Brightness matching against a 150 ms referent stimulus that was projected at a dot luminance of 0.429 cd/m². These scores reflect the intensity of the intensified part of the target stimulus:-

Intensified duration (ms)	Intensified dot luminance (cd/m²)			
	SYB	DFS	LMG	PAR
10	3.230	3.230	3.230	2.770
30	1.279	1.279	1.573	1.279
50	0.661	0.827	1.027	0.827

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