information as their basis for selection. Partial report performance in this condition was nevertheless better than predicted at short cue delays. The findings converge to suggest that subjects can use the stimulus attributes of perceived size to selectively extract information from iconic memory. As such, they imply that the information that can be represented within this early visual store is not solely retinotopic. It is therefore proposed that a multicomponent view, encompassing both retinal and post-retinal contributions to the icon, may provide a more adequate theoretical conceptualization of iconic memory than is presently available.

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Chapter 1

ICONIC MEMORY: A REVIEW OF THE STUDY OF A TRANSIENT VISUAL STORE

Introduction: Sperling's (1960) Seminal Contribution - The Partial Report Paradigm

Within the past two decades, a general metatheoretical view of visual information processing has emerged. This view is based on the idea of sequentially dependent stages (e.g., Haber, 1969, 1974; Lachman, Lachman, and Butterfield, 1979; Lindsay and Norman, 1977; Massaro, 1975) or processes, each of which requires a finite amount of time and by which information about a stimulus is transformed, encoded, and possibly stored. The earliest stage of processing is generally referred to as "iconic memory" (Neisser, 1967), and much of this concept's popularity in the currently dominant information-processing approaches to visual perception can be attributed to the seminal work of Sperling (1960).

Sperling (1960) demonstrated that for a short duration following the physical termination of a briefly presented display of alphabetic characters, more information is available to observers than they can normally report. In one part of Sperling's original work, he displayed letter arrays of various sizes and configurations for brief periods of time and asked observers to report as many letters as possible (the whole report procedure). He found that observers could maximally report four or five letters from the entire display. Sperling showed, however, that this limitation in report could be effectively circumvented by cueing observers to selectively report only a subset of the letters from the visual display (the partial report procedure). For example, stimulus displays consisted of either 3 x 3 or 3 x 4 arrays of letters that were presented for 50 msec. Following the offset of the display by some variable interstimulus interval (ISI), a high, medium, or low tone was presented which cued the observer to report either the top, middle, or bottom row of letters in the display, respectively. Since the observers did not know prior to stimulus offset which particular row would be cued for report, Sperling argued that the proportion of letters in the cued row that they were successfully able to report following the cue reflected directly the proportion of information from the entire display that was potentially "available" to them at the moment of the cue. Sperling found that if the cue immediately followed the offset of the display, almost all of the letters (i.e., 76% or 9.1 out of 12) were able to be reported correctly. This superiority of partial report performance over whole report performance, however, decreased rapidly with an increase in cue delay. By about one second delay between display offset and cue presentation, partial report performance had asymptoted to a level that did not differ significantly from estimates obtained with the whole report procedure. Sperling hypothesized that this superiority of the partial report over the whole report and the accompanying decrease in the effectiveness of the partial report as the cue was delayed depicted the rapidly decaying amount of information available to the observer over time from what he called the "visual information store" (Sperling, 1960, p. 22). This transient visual storage of information was later theoretically elaborated upon and coined "iconic memory" by Neisser (1967).

In an often-cited parallel to Sperling's classic work, Averbach and Coriell (1961) employed an alternate form of Sperling's partial report procedure to assess various aspects and properties of iconic memory. They presented a 2 by 8 array of letters and used a visual bar marker to cue only one letter for report. Like Sperling before them, Averbach and Coriell found that the probability of correct recall for the letter in the cued location was nearly perfect with immediate cues, and decreased monotonically with increasing cue delays up to 250 msec.

The results of both classic poststimulus sampling experiments tend to complement one another rather well (cf. Dick, 1974). Both studies indicate that the initial visual persistence that produced the partial report superiority was of a relatively brief duration, and suggest that the information was immediately available but decayed rapidly. The finding of a partial report superiority that diminishes as a function of increasing cue delay has been the principal evidence for postulating the existence of iconic memory (see Coltheart, 1975, for a review).

Forms of Information in Iconic Memory, and Empirical Findings with Sperling's Paradigm

Since the publication of Sperling's (1960) influential monograph, there have been numerous replications of his findings, typically in the context of studies examining the effect of some variable or parameter on iconic memory. For example, a large body of research has been concerned with determining the effectiveness of various stimulus attributes that can be used by observers to select information from iconic memory and, by inference then, the forms of information that can be represented within this early visual store. In Sperling's experiments, observers were able to selectively process information from the visual displays on the basis of spatial location (i.e., row position), suggesting that spatial location information is preserved in iconic memory. Briley (1972) and Turvey (Note 1), 1

among others, have since replicated this finding. Sperling (1960) also attempted to determine whether observers could utilize higher order or postcategorical stimulus attributes such as class or category (i.e., letters vs. digits) to select information from iconic memory. Sperling found that selection on the basis of such stimulus attributes was generally ineffective; recall performance was no more accurate with the partial report procedure than it was with the whole report procedure. This finding, which has been replicated several times by other investigators (e.g., Dick, 1969, 1971; von Wright, 1970, 1972), has been used to argue for the unprocessed, precategorical nature of the information that can be represented in iconic memory.

A recently published study by Merikle (1980), however, has apparently produced some evidence that is inconsistent with the precategorical conceptualization of iconic memory. Merikle found that partial report cues based on category membership (i.e., letters vs. digits) produced a partial report superiority which decreased with increased cue delay. This standard effect, however, was observed only when the cued subset of letters or digits was correlated with a physical dimension (filled or outlined items). Furthermore, in one instance, the partial report cues were presented considerably before display onset (2,000 msec).

He concluded on the basis of this evidence that iconic memory should not be characterized as precategorical or literal in nature. Given the rather unusual methodology, nature of the data, and the amount of other data supporting the opposite conclusion, judgement must be reserved at present on the interpretation to be placed on Merikle's data.

Notwithstanding the arguments of Merikle (1980), the conclusion that has been drawn by a majority of investigators is that the extraction of visual information from iconic memory can be performed efficiently on the basis of simple physical characteristics and properties of the stimulus, but not on the basis of more complex semantic or categorical abstractions. This conclusion is supported in part by the kinds of selection criteria that have resulted in a partial report superiority in Sperling's (1960) paradigm. Although partial report cueing by spatial location has generally been found to be the most effective basis of selection in iconic memory (e.g., Bongartz and Scheerer, 1976; von Wright, 1968, 1970), partial report superiorities have been obtained with a variety of visual selection cues. These include: color (Banks and Barber, 1977; Clark, 1969; Coltheart, Lea, and Thompson, 1974; Turvey, Note 1; von Wright, 1968), brightness (von Wright, 1968), size (von Wright, 1968), shape (Triesman, Russell, and Green, 1975;

Turvey and Kravetz, 1970), direction of linear and rotary motion (Demkiw and Michaels, 1976; Triesman et al., 1975), flicker (Russell, cited in Coltheart, 1980a,b), and rectangular pattern information (Marzi, Di Stefano, Tassinari, and Crea, 1979).

Research on iconic memory has not been limited only to studies investigating the effectiveness of various selection cues in Sperling's (1960) partial report paradigm. Indeed, research on iconic memory has been extremely diversified. For example, a number of studies have examined the effects of repetition of display items on partial report performance (e.g., Merluzzi and Johnson, 1974; Standing and DaPolito, 1968; Turvey, 1967), and have found none. Other studies have found little or no effects of approximation-to-English of the letters in the stimulus displays (Mewhort, 1967), slight effects of visual field presentation (Marzi et al., 1979), but a very pronounced left-to-right directionality in processing information out of iconic memory (Lefton and Spragins, 1974; Lefton, Fisher, and Kuhn, 1978; Mewhort, Merikle, and Bryden, 1969). Other representative studies employing Sperling's paradigm have found iconic memory to be very sensitive to stimulus background levels (Sperling, 1963) and extremely susceptible to visual masking (Averbach and Coriell, 1961; Averbach and Sperling, 1961; Spencer, 1969; Sperling, 1963) and dichoptic interference (Averbach and Coriell, 1961; Erwin and Hershenson, 1974; Jacewitz and Lehmann, 1972). In addition to these findings, Chow and Murdock (1975, 1976) and Doost and Turvey (1971) have found that retention of information within iconic memory is not impaired by concurrent or subsidiary tasks that have been shown to tax processing capacity. Similarly, Scarborough (1972) found that information in the icon is not subject to auditory interference, while Wickelgren and Whitman (1970) have shown that information in iconic memory does not exhibit any associative effects. In recent reviews of iconic memory, Dick (1974) and Coltheart (1980a,b) have discussed many of these findings within the extensive partial report literature.

The view that has emerged from this massive amount of empirical work is that iconic memory is a high capacity, centrally-located memory which contains a visual representation of the stimulus that is literal, precategorical, wholistic, maskable, and subject to fairly rapid, passive decay (Coltheart, 1975; Dick, 1974). The estimated storage time of iconic memory has been inferred to be on the order of 250-300 msec (Averbach and Coriell, 1961; Haber and Standing, 1969; Vanthoor and Eijkman, 1973).

The conventional view of iconic memory as a rapidly decaying visual trace has been formalized by Rumelhart (1970).

and Norman and Rumelhart (1970) in a mathematical model of letter recognition under tachistoscopic viewing conditions. This model assumes that at the onset of physical stimulation, a representation of the physical stimulus is registered in iconic memory and that the clarity of the information in this early visual store decays away exponentially with time. In later stages, visual information is extracted from this decaying trace.

It has been suggested that what decays in iconic memory is information about such physical stimulus attributes as spatial location or color, while information about the identity of an item is also represented in iconic memory but does not decay. Such a view has been endorsed by Dick (1969) and Townsend (1973). They have independently demonstrated that identity information does not decay, while spatial information does; as cue delay is increased, more and more often what an observer knows about a certain letter is that it was in the display but not where it was in the display. This conclusion is supported by the finding that the rate of intrusion errors (incorrect reports of letters not present in the display) does not vary as a function of cue delay, but that the rate of transposition errors (reporting a letter which was in the display but not in its correct serial position) does increase with increasing cue delay. This finding has since been replicated by Di Lollo (1978) and Mewhort, Campbell, Marchetti, and Campbell (in press).

Unresolved Issues

The preceding description has presented an oversimplified and somewhat misleading picture of the current status of empirical research and knowledge about iconic memory. It appears fairly well established that a brief visual stimulus leaves a trace which decays rapidly during a period of several hundred milliseconds after its physical offset. What is not known is whether information in iconic memory decays probabilistically or temporally, all-or-none or continuously. Despite the hundreds of empirical studies that have been conducted during the past two decades, serious controversy and heated debate still exist concerning numerous aspects of iconic memory. These include, for example, the types of information that can be represented or coded within iconic memory, its sensitivity to various stimulus parameters, such as luminance (e.g., Adelson and Jonides, 1980; Sakitt, 1976a; Scharf and Lefton, 1970) or duration (e.g., Di Lollo, 1978; Sakitt, 1976a; Sperling, 1960), its location within the visual system (e.g., Adelson and Jonides, 1980; Banks and Barber, 1977; Sakitt, 1975, 1976a), and its function in general on perceptual tasks.

This chapter has dealt with only those findings that have been obtained with the partial report paradigm. This procedure is by its very nature, an "indirect" method for investigating visual persistence (iconic memory). Numerous other more "direct" experimental procedures (e.g., Haber and Standing, 1969) have also been widely employed, a review of which can be found in Coltheart (1976, 1980a,b). There is good reason to suspect, however, that other methodologies that have been used have not really examined iconic memory per se, but some other form of visual persistence effect. In two recent discussions of the visual persistence literature, Coltheart (1980a,b) has distinguished three distinct senses in which a stimulus may be said to persist after its physical offset. First, the stimulus may continue to be visible or phenomenologically present for some time after its physical termination (visible persistence). Second, the neural activity in the visual system evoked by the stimulus may continue after stimulus offset (neural persistence). Finally, the visual information contained in the stimulus may continue to be available for some time after the physical termination of the stimulus (informational persistence). Coltheart has argued strongly and provided compelling evidence to suggest that each form of persistence has its own empirical support, that the three are often confused and muddled in general discussions of iconic memory, and that the relation among the three forms of visual persistence represents an unsolved empirical question. He has argued extensively that informational persistence is defined by the use of the partial report procedure, and that the term "iconic memory" should be used to describe only this form of visual persistence (but see Long, 1980, for a critique of Coltheart's conclusions). In line with Coltheart's cogent arguments, it is believed that the use of various incomparable and nonequivalent methodological procedures has contributed immensely to the often discrepant and even contradictory results that one finds in the iconic memory literature.

The partial report paradigm has not, however, been without its critics. Several strong objections have been raised, in the contexts of whether iconic memory exists at all, and whether the partial report superiority effect truly reflects iconic memory. These objections have been reviewed elsewhere (Coltheart, 1975; Dick, 1974; Holding, 1975). Other criticisms that have been leveled against the use of the partial report paradigm include its susceptibility to cue interpretation difficulties (e.g., Eriksen and Collins, 1969), its overestimation of the duration of iconic memory (Appelman, 1980; Sakitt and Appelman, 1978), its exclusive use of alphanumeric stimuli (e.g., Haber and Hershenson, 1973, 1980; Kaufman, 1974), and its susceptibility to output interference (Holding, 1970, 1975) and cue anticipation (Holding, 1970, 1971, 1973, 1975). The advocates for the partial report paradigm have, for the most part, been able to contend adequately with these potential confounding problems and criticisms (see Coltheart, 1975; Crowder, 1976; for reviews), and this paradigm remains the most widely used sampling procedure investigating iconic memory to date. The viewpoint accepted here is that the partial report superiority effect satisfactorily reflects the processes underlying iconic memory.

Having outlined the properties of iconic memory and some of the objections that have been raised with respect to the use of the partial report paradigm, the following chapters will examine the issue of the suspected neural locus of this early informational store in the visual system. This issue has become of late a major focus of intensive research and a lively source of serious controversy that has yet to be adequately resolved. Establishing whether the icon is located peripherally, at the level of the retina, or more centrally, is an important question both in its own right and because it provides valuable information about the storage capacity and strength of the visual system at its various stages or levels.

Chapter 2

SAKITT'S WORK AND THE RETINAL LOCUS OF ICONIC MEMORY

The dominant view in the past has been that iconic memory represents a central but relatively early stage in the visual system that serves to prolong transient visual events (Coltheart, 1975; Dick, 1974). Within the last few years, however, there has arisen increasing evidence that such a conceptualization of iconic memory may be incorrect. In a series of experiments, Sakitt (1975, 1976a) demonstrated the existence of a robust iconic storage in the retina in the form of photoreceptor persistence. Sakitt has argued that the icon is a weak afterimage localized in the rod photoreceptors, and has proposed that these photoreceptors exhibit sufficient persistence effects (Sakitt, 1976b) to account for the bulk of results generally considered to support the notion of iconic memory. In a sense, this view "argues against the 'memory' aspect of so-called iconic memory along the same grounds that afterimages are not considered true memory effects" (Long, 1980, p. 788). Despite the widespread nature of this claim, however, it has never been investigated or defended except by Sakitt and her colleagues, whose work is discussed below.

Sakitt (1975, 1976a) conducted a series of Sperling-type experiments with a rod monochromat observer (who has normal rod vision but no functional cone vision) and was able to obtain apparently normal partial report results. She showed that letters in a stimulus display that were initially invisible to the observer, due to rod saturation, became visible after the rod monochromat closed her eyes. Since the letters were eventually discriminable, Sakitt contended that the information about the letters must have been stored prior to the first stage in the visual system that saturates. She explained this finding by arguing that those rods that were exposed to both the letters and the background had more activity in them, and therefore, produced larger signals, than those exposed only to the background. This allowed the icon to emerge from the background when the rod monochromat closed her eyes. Sakitt also found that the magnitude of the partial report superiority increased with the intensity of the stimulus, and that the obtained decay functions were slower when the pre- and postadapting fields were dark. Furthermore, when icon brightness was equated across visible wavelengths, the spectral sensitivity data of the rod monochromat closely resembled those of normal observers for scotopic (rod) vision. On the basis of these results, Sakitt hypothesized that most or all of the information about the icon is stored within the rod photoreceptors.

Empirical Support for a Retinal (Rod) Interpretation of Iconic Memory

Electrophysiological recordings by Whitten and Brown (1973a,b,c) of the late receptor potential of rods and cones in the macaque monkey (whose retina is very similar to that of the human), as well as in other species (cat, rat, mudpuppy) by Fain and Dowling (1973), Penn and Hagins (1972), and Steinberg (1969), respectively, have shown that after stimulus offset, both the rods and the cones continue to output signals for some time. The cone signal, however, decays away rapidly, whereas the rod signal decays with a longer time constant. Sakitt's hypothesis that iconic memory is primarily a rod photoreceptor persistence effect is consistent with these single-cell findings to the extent that neural information is apparently available for a longer duration for the rods than it is for the cones.

The electrophysiological findings discussed above are paralleled by several psychophysical results in the human. Sakitt's contention of a dominant rod contribution to iconic memory is supported in part by Adelson's (1978) finding that stimuli discriminable only by the cones do not persist for as long as stimuli discriminable by the rods. Long (1979a), Long and Sakitt (1980a), and Sakitt and Long (1978, 1979) have also demonstrated that under apparently normal conditions of light adaptation, iconic memory appears to have a short cone component for ISIs roughly up to 100-200 msec, and a longer lasting, more robust rod component for longer ISIs.

Indirect support for a retinal interpretation of iconic memory has also come from several studies examining the relationship between saccadic eye movements and visual masking. Using a backward masking paradigm with either a visual pattern mask or a metacontrast annulus, Davidson, Fox, and Dick (1973) found both types of masks to be most effective when they stimulated the same retinal location rather than the portion that was in the same location both objectively and apparently. Furthermore, masking was found to be weaker when an eye movement intervened between the stimulus and the mask. A subsequent experiment by Doerflein and Dick (Note 2) confirmed that the icon moves in the direction of the eye movement. These data suggest that an eye movement per se does not erase the icon; an eye movement merely "moves" the iconic representation relative to the physical world.

Both eye movement studies are generally consistent with Sakitt's hypothesis since they indicate that the icon moves when the eye moves, instead of remaining in the location where the stimulus was presented. This suggests that the icon is stored at a level in the visual system that has a retinotopically-organized coordinate system.

rather than a spatiotopically-organized coordinate system more typically characteristic of visual perception (where images do not change their perceived location simply because the eye moves).

If Sakitt's hypothesis is correct, a photoreceptor interpretation of iconic memory would be expected to demonstrate a predictable sensitivity to manipulations in stimulus energy. Given the luminance-duration reciprocity (Bloch's Law) observed in retinal processes up to a critical duration (cf. Ganz, 1975; Graham, 1965), the effects of increasing either stimulus luminance or stimulus duration on iconic memory should be identical: An increase in either of these energy variables would be expected to increase the activity and duration of photoreceptor output (at least up to a point). Such positive, monotonic relationships have been observed (e.g., Keele and Chase, 1967; Long, 1979a; Long and Sakitt, 1980a,b; Sakitt, 1976a; Sakitt and Long, 1978, 1979), and are consistent with an energy-dependent conceptualization of iconic memory (see also Eriksen and Schultz, 1978, for a comprehensive review). A significant number of other studies, however, have reported iconic memory to be either independent of, or inversely related to, manipulations in stimulus luminance and stimulus duration. Such findings pose serious empirical and theoretical difficulties for the retinal interpretation of iconic memory, and will be examined next.

Evidence Against or Inconsistent with a Retinal (Rod) Interpretation of Iconic Memory

A number of investigators employing the partial report paradigm have reported the icon to be rather insensitive or invariant to changes in stimulus luminance, provided of course, that the luminance is sufficiently high to ensure full and proper legibility of the visual display initially (Adelson, Note 3; Adelson and Jonides, 1980; Eriksen and Rohrbaugh, 1970; Scharf and Lefton, 1970; Sperling, 1963). For example, Adelson and Jonides (1980) recently found that although stimulus luminance was varied from very dim (8.7 ml) to very bright (70 ml), partial report performance decayed at similar rates for each level of stimulus luminance. The results of this study, along with those of other studies reporting similar findings, are inconsistent with a strictly energy-dependent, rod-photoreceptor conceptualization of iconic memory.

Several studies have also reported limited or no stimulus duration effects on iconic memory. Sperling (1960, Figure 4) found that increases in stimulus exposure duration over the range of 15 to 500 msec produced no systematic changes in the level of performance in the partial report. Similarly, Di Lollo (1978) investigated the effects of stimulus duration on partial report performance and found that performance was essentially identical with stimulus display durations of 100 and 200 msec. Again, these results are inconsistent with Sakitt's photoreceptor interpretation of iconic memory since they indicate that iconic memory is largely invariant to changes in exposure duration. If iconic memory were intimately related to ongoing neural activity in the photoreceptors, one would expect that as stimulus duration increased, the duration of the icon would also increase, due to prolonged retinal activity.

Interestingly, it should be noted that a number of researchers have also reported an inverse relationship between luminance and duration manipulations and their resulting effects on visual persistence (e.g., Bowen, Pola, and Matin, 1974; Briggs and Kinsbourne, 1972; Di Lollo, 1980; Efron, 1970a,b,c; Haber and Standing, 1969, 1970). A major problem with these studies, however, is that they all employed different methodologies for investigating visual persistence, and that these methodologies in particular exhibit potentially serious weaknesses or at least potentially confounding aspects that must serve to temper any conclusions about the form of visual persistence based upon them (see Coltheart, 1980a, for a discussion of these problems). Furthermore, none of the studies that have found an inverse relationship have employed the partial report paradigm. In line with Coltheart's (1980a,b) cogent arguments, these studies did not investigate iconic memory and hence, the relevance of these studies to a discussion of iconic memory is equivocal at best.

Sakitt's hypothesis that the rods alone mediate iconic memory has also been contested by Adelson (1978). Utilizing the partial report paradigm, he tested the hypothesis by presenting letters of one color against a nonoverlapping field of another color. The colors were chosen as to be discriminable only by the cones (because the letters were scotopically matched to the background), only by the rods (a color-blind observer, a protanope, took part in the experiment), or both. In all three stimulus conditions, the data revealed a partial report superiority which declined with increasing cue delay. Moreover, the partial report decay functions for the rods-only and the cones-only conditions were very similar. This suggests that the rods are not necessary for iconic storage; stimuli discriminable only by the cones yield appreciable persistence times. The cones, however, are not necessary either, since the results obtained with the protanope show that stimuli discriminable only by the rods also persist visibly for considerable durations. Thus, the important point that

Adelson has successfully demonstrated is that iconic memory is a property of both the rod and the cone system.

Recently, Banks and Barber (1977) have also questioned the validity of Sakitt's hypothesis. They have reported compelling evidence for extensive color information in iconic memory lasting for hundreds of milliseconds, from which they argue that iconic memory cannot be primarily a rod, and therefore, colorless, visual phenomenon. As such, it need not necessarily be of peripheral origin either. Banks and Barber found that when the letters and the background in stimulus displays were scotopically matched for differences in brightness, the letters could be discriminated only by the cones. They proposed that iconic memory, like normal vision, obtains most of its information from the rods in dim light and from the cones in bright light. Thus, both systems appear to be involved.

Sakitt and Long (1979) have raised the possibility that both sets of results are spurious and inconclusive. Specifically, they have argued that both Adelson and Banks and Barber made sufficiently large calibration errors such that the scotopic matches they claimed to have made were significantly off. Thus, the selection of color information from iconic memory in their experiments might have been accomplished on the basis of differential scotopic brightness discrimination.

Mollon and Polden (1978) have also argued against the conclusions of Banks and Barber (1977) on the grounds that both the rise and fall times of the tachistoscopic lamps they used are different for different wavelengths of the lamps' luminous output when stimulus exposure duration is short. Therefore, Mollon and Polden claim that scotopic discrimination of the letters from the background may have been possible with the 50-msec exposure duration that Banks and Barber used in their study.

In a rebuttal to both these serious accusations, Adelson (1979) and Banks and Barber (1980) recently demonstrated in independent studies that small discrepancies from perfect scotopic matching of the letters and the background in a stimulus display are not sufficient to make the letters visible to the rods. In addition, letters under these stimulus conditions are not visible to a rod monochromat, even with brief stimulus exposure durations (Banks and Barber, 1980).

In sum, it would appear that iconic memory can exist for stimuli that the rods cannot discriminate. It also appears unlikely that the rods are involved in iconic memory experiments that utilize stimulus conditions of high illumination. It is known, for example, that the rod system saturates at roughly 1,000 scotopic trolands (Anguilar and Stiles, 1954; Blakemore and Rushton, 1965), so that at intensities above this critical saturating level, there is essentially no rod icon (Sakitt, 1976a). In the classic study of Averbach and Coriell (1961), the adapting fields were bright enough (70 ftL) to keep the rods saturated throughout their experiment. (In fact, the luminance level they used was approximately 1,000 times higher than the level needed to saturate the rods). It is very difficult to imagine how a pure rod afterimage, in Sakitt's sense, could have been the source of the partial report superiority effect observed in Averbach and Coriell's study.

Current Status of the Retinal Hypothesis

This chapter has focused exclusively on those studies whose empirical findings are supportive of, or inconsistent with, an interpretation of iconic memory based solely on the ephemeral persistence of the rod photoreceptors. Clearly, the bulk of the evidence reviewed in this chapter suggests that iconic memory can have a retinal locus. It also suggests that both the rods and the cones may be intricately involved. The critical experiment determining the exact contribution of each, however, has yet to be performed. Furthermore and more importantly, recent work demonstrating that the rods' output is inhibited by the output of the cones (e.g., Makous and Boothe, 1974;

Stabell and Stabell, 1976, 1977) would seem to question the existence of an "unambiguous" rod or cone icon.

The following chapter will examine evidence from a variety of other experiments that suggests the possible contribution of active postretinal or more central components in iconic memory. It is hoped that such a discussion will demonstrate the current state of empirical and theoretical uncertainty surrounding the phenomenon, and help to clarify the perennial controversy concerning the neural locus of iconic memory within the human visual information processing system.

Chapter 3

POSTRETINAL CONTRIBUTIONS TO ICONIC MEMORY

The preceding chapter examined several lines of evidence that indicate that iconic memory can be peripherally based in the retina (both in the rod and cone photoreceptors). It appears very unlikely, however, that any model of iconic memory based solely on photoreceptor persistence can adequately accommodate all of the findings that have been reported in the literature within the last 15 to 20 years. Therefore, this chapter will concentrate on those studies whose findings suggest that iconic memory also involves active contributions from components operating postretinally in the visual system. Iconic memory, like other visual phenomena, such as masking, may contain both peripheral and central contributions (e.g., Turvey, 1973, 1978); the particular stimulus conditions may determine which is evidenced. The possibility of multiple loci has been proposed previously (Crowder, 1976).

Iconic Memory for Movement Information

Several investigators (Demkiw and Michaels, 1976; Russell, cited in Coltheart, 1980a,b; Triesman et al., 1975) have reported that the direction of linear and rotary movement can be processed in iconic memory. They have shown that when a visual display of moving stimuli is presented and subsequently followed by a cue requesting the report of the direction of movement of the cued stimuli, typical partial report results are obtained. This finding of a decaying partial report superiority with increasing cue delay for direction of movement strongly suggests that the representation of movement information in iconic memory can occur at least at the level of feature detectors, which for the monkey, and by inference, the human, is almost certainly postretinal (Hubel and Wiesel, 1960, 1968; Schiller, 1972). Physiological movement detectors selectively sensitive to the direction of movement have also been observed in the optic tectum of the frog (Lettvin, Maturana, McCulloch, and Pitts, 1959) and visual cortex of the rabbit (Barlow and Hill, 1963; Barlow and Levick, 1965) and cat (Albus, 1980). From these and other representative single-cell data, it would appear extremely improbable that a retinal icon could preserve dynamic information about the direction of movement.

Central, Spatiotopic Processing of Eye Movement Information in Iconic Memory

The saccadic eye movement studies of Davidson et al. (1973) and Doerflein and Dick (Note 2) were discussed in the previous chapter as providing indirect support for the retinal interpretation of iconic memory. In these two studies, masking was found to be dependent on retinal location; the effect of the visual mask was to suppress the report of the letter that stimulated the same retinal location, but occupied a different spatial position within the letter array. They also found that the icon moves with the eye.

These findings are in contrast with several results reported by Hall (1974) and Ritter (1976). Employing the partial report paradigm, Hall (1974) found that observers tended to move their eyes to the position in space that corresponded to that part of the stimulus display that was being indicated for recall by an auditory cue. He interpreted his results as indicating that observers spatially scan the icon by making an eye movement. Ritter (1976) demonstrated that stimuli received prior and subsequent to a saccadic eye movement are processed in iconic memory according to their veridically perceived location within the visual display.

White (1976) has also reported findings that contrast sharply with those of Davidson et al. (1973) and Doerflein and Dick (Note 2). He found that visual masking during smooth pursuit eye movements depends on the apparent position of the stimuli, not on their retinal position. Masking stimuli were more effective when they appeared in the same place as the target stimulus but stimulated different parts of the retina than when they stimulated the same retinal loci but appeared displaced due to an intervening smooth pursuit eye movement. This finding has since been replicated and confirmed with saccadic eye movements by White and Holtzman (Note 4) and White and Wong (Note 5). These results suggest that at least some varieties of visual masking depend on apparent spatiotopic rather than on retinotopic processes.

The findings of studies reported in this section suggest a central location of iconic memory and the processing of eye movement information within this early visual store. The reasons for the unusually large discrepancies in the results across eye movement studies, however, remain unclear at present.

Susceptibility of Iconic Memory to Dichoptic Masking

The susceptibility of the decaying icon in one eye to masking by a stimulus presented simultaneously to the other eye (dichoptic masking) has been used as critical evidence for a postretinal or central locus of iconic memory (e.g., Erwin and Hershenson, 1974; Jacewitz and Lehmann, 1972). For example, Jacewitz and Lehmann (1972) presented a typical Sperling (1960) partial report task to an observer's left eye while varying the input to the right eye from that of a homogeneous, dark field (no interference) to a stroboscopic train of alternating light and dark flashes or grid flashes. For the partial report task, nine letters in a 3 x 3 matrix were presented for 50 msec, followed at some brief temporal delay by a variable-pitched tone that cued the observer to report the top, middle, or bottom row of letters only. In comparison with the no-interference condition, they found that the level of partial report performance decreased markedly with an increase in the complexity of the contra-ocular signals. This trend was clear at any given cue delay, but particularly evident and large at the short delays. Jacewitz and Lehmann interpreted their findings in terms of reduced central processing capacity available, and thus concluded that at least some portion of iconic memory is centrally located.

Dick (1974) has argued that since dichoptic presentation produces masking, the results of these studies imply that the icon cannot be retinal, but must be cortical. The validity of this argument, however, rests on the assumption that dichoptic masking effects occur within and not subsequent to iconic memory as suggested by Turvey (1973). In the context of postulating the neural basis of iconic memory, Sakitt (1976a) made the distinction between the physical location of iconic memory and the locus of the perception of the icon itself. She suggested that the peripheral locus of the icon can be reconciled with the results of dichoptic masking experiments if it is assumed that a persisting visual signal on the retina continues to transmit information to higher visual centers throughout its existence. Given a persisting neural representation of the target on the retina in one eye, the presentation of a mask to the contralateral eye within a suitable temporal interval may interact with information about the target at a site where binocular interaction occurs, thus producing masking-like effects. As such, the conclusion that iconic memory is necessarily centrally located is not warranted on the basis of evidence obtained from dichoptic masking studies.

Stereopsis and Iconic Memory

In recent years, several studies have investigated the possible representation of postretinal information in iconic memory by assessing the effectiveness of stereoscopically perceived depth as a selection cue in Sperling's (1960) partial report paradigm. Essentially, the underlying logic behind these experiments has been that if information about stereoscopic depth can be processed within iconic memory, then this suggests that such stimulus attributes are represented within this early visual store, and implies that iconic memory cannot be solely a retinal persistence phenomenon.

This view is consistent with a number of lines of evidence which suggest that the processing of stereoscopic depth is accomplished by centrally-mediated mechanisms. Julesz's (1960, 1964) early work with random-dot stereograms demonstrated that the binocular assessment of perceived depth does not require the prior recognition of form, suggesting that disparity information is processed centrally in the brain fairly early in visual perception. The temporal course for the development of stereoscopic depth in random-dot stereograms has been inferred to be on the order of approximately 50 msec (Julesz, 1964; Uttal, Fitzgerald, and Eskin, 1975).

Neurophysiological studies by Barlow, Blakemore, and Pettigrew (1967) and Nikara, Bishop, and Pettigrew (1968) have described a group of cells in the cat visual cortex that responds selectively to horizontal disparate stimulation of the two retinas. Hubel and Wiesel (1970) have also provided supporting evidence for the existence of similar cells in Area 18 of the macaque monkey cortex, and Bough (1970) has succeeded in providing compelling behavioral evidence for stereoscopic vision in macaque monkeys. Furthermore, several recent psychophysical studies have implied the existence of disparity-specific neurons in the human visual system (e.g., Blakemore and Hague, 1972; Felton, Richards, and Smith, 1972; Mitchell and Baker, 1973) similar to those observed in the cat and monkey visual cortex. Therefore, inasmuch as stereoscopically perceived depth cannot be based upon a single proximal stimulus (i.e., retinal image), the ability of observers to effectively utilize perceived depth as a selection cue for recall would suggest more central processing of information in iconic memory.

Fox, Lehmkuhle, and Shea (Note 6) employed the technique of random-element stereograms developed by Julesz (1960, 1964) to present brief 3 x 5 matrices of letters that could not be discriminable with monocular vision. Following the standard partial report procedure, one of the three rows of letters was cued for report after stimulus offset. Fox et al. found no evidence for partial report superiority at any cue delay for the stereoscopic displays. They concluded that information about stereoscopic depth is not processed within iconic memory.

The results of this study suffer from several difficulties. First, Fox et al. did not specify the extent to which their observers were practiced in discriminating stereoscopic forms in their random-dot stereograms. Julesz (1971) has reported that with sufficient practice, observers can readily learn to discriminate depth in such stimulus situations. Second, the task of identifying stereoscopic letters may have been very time consuming. Given that the representation of information in the icon decays rapidly, observers may not have had sufficient time to effectively decode the cue and subsequently utilize it to report the letters. Thus, in their experiment, the amount of information that could have been extracted from the visual display may have been so small as not to be evident in a comparison of partial with whole report performance.

Macleod (Note 7) also conducted an experiment to establish whether stereoscopically perceived depth could cue a partial report superiority in a Sperling-type situation. The stimuli consisted of twelve letters in a 3 x 4 matrix that were presented in stereoscopic depth for a duration of 100 msec. His observers were instructed to report letters on the basis of their spatial location (top, middle, or bottom row) in one condition, and on the basis of their respective perceived depth (near, plane, or far row) in another condition, after the presentation of an auditory cue. Macleod obtained a partial report superiority when the cues indicated spatial location, but failed to obtain a similar effect when the cues signalled perceived depth. He concluded, therefore, that stereoscopic depth information cannot be processed in iconic memory.

His results, however, are also open to a number of serious methodological difficulties (see Mustillo, Note 8, for a full discussion).

Recently, Mustillo (Note 8) and Mustillo and Komoda (Note 9) have reported several findings that contrast with the earlier results and conclusions of Fox et al. (Note 6) and Macleod (Note 7). In order to assess the efficacy of stereoscopically perceived depth as a selection cue, two rows of eight letters were constructed such that they had different depth values. In one condition, observers were cued according to the perceived depth of the rows (nearer or farther), while in the second condition, they were cued according to the spatial location of the rows (top or bottom). Stimulus configurations were identical in both conditions, and the stimulus displays were presented for 50 msec, followed at some variable temporal delay by an auditory cue. These investigators found some promising indications that observers could utilize information about stereoscopically perceived depth to select letters from iconic memory, although the magnitude of the partial report superiorities that they obtained was small in the stereoscopic depth condition. They hypothesized that this may have been due to the additional processing time that is required by observers to decode the cues when they signal perceived depth, and/or the appreciable amount of time it may take for stereoscopic depth to develop in such stimulus situations.

The findings of Mustillo (Note 8) and Mustillo and Komoda (Note 9) suggest that retinal disparity information may be processed within iconic memory, and reinforce the view that the information that can be represented within iconic memory is not solely retinotopic. Iconic memory may also include significant contributions from more central components operating at higher levels in the visual system where information from both eyes is integrated. Clearly, however, further research is needed in order to strengthen this conclusion.

Conclusion

It would appear from an examination of the studies presented in this chapter that iconic memory cannot be conceptualized solely as a retinally-based persistence phenomenon. Those studies that have reported that information about the direction of movement is subject to a similar pattern of decaying partial report superiority that Sperling (1960) originally found with static information are difficult to reconcile with a purely retinal locus of iconic memory. Similarly, the eye movement studies described in this chapter, along with the recent findings that suggest that iconic memory may be able to preserve stereoscopic depth information induced by the disparity between the points of stimulation in both eyes, also pose serious empirical and theoretical difficulties for the view that iconic memory is merely a weak after-image localized in the photoreceptors of the retina. Those studies that have shown iconic memory to be particularly vulnerable to dichoptic interference, however, may be open to alternative interpretations: The possibility exists that a peripheral icon, in Sakitt's sense, could still forward information to some more central locus where the interaction between the target and the mask could take place. In all, the bulk of the evidence reviewed in this chapter suggests that iconic memory may contain postretinal contributions.

Chapter 4

SELECTION OF INFORMATION FROM ICONIC MEMORY ON THE BASIS OF STEREOSCOPICALLY PERCEIVED SIZE

The foregoing discussion has had three principal objectives, each represented and developed in one of the three preceding chapters. In chapter 1, an attempt was made to describe the seminal work of Sperling (1960) and the pivotal position it has since occupied in the information-processing literature in initiating the current interest and serious research on iconic memory. The properties of iconic memory were described in the context of the massive amount of empirical evidence obtained with the partial report paradigm, and methodological criticisms against its use were briefly reviewed. The first chapter ended with a brief delineation of some unresolved issues related to the study of iconic memory.

The rather lengthy second chapter consisted of a description of Sakitt's influential work and its implications for the neural locus of iconic memory. Evidence from a variety of studies was presented which is consistent with or difficult to account for simply in terms of the conceptualization of iconic memory based solely on the persistence of the rod photoreceptors in the retina. In the third chapter, several lines of evidence were reviewed that suggest the possible contribution of postretinal processing in iconic memory.

The results of the studies examined in chapters 2 and 3 need not be viewed as necessarily contradictory. While the icon may be physically "stored" on the retina, as Sakitt's work strongly suggests, postretinal or more central processing of the information in the icon may still be required for its successful extraction. Indeed, a number of recent discussions related to this issue (e.g., Crowder, 1976; Long, 1979b; Michaels and Turvey, 1979; Turvey, 1978) have iterated and expounded similar theoretical positions. The experiment to be reported in this chapter will attempt to further substantiate this claim by systematically assessing whether information about stereoscopically perceived size can be processed within iconic memory.

General Introduction to the Present Empirical Study

A substantial amount of quantitative evidence for the existence of iconic memory has been accumulated since Sperling's germinal research 20 years ago. Despite this extensive empirical effort, however, there is still serious controversy concerning several aspects of iconic memory, particularly its physical location within the visual system. Although Sakitt's work has provided the most compelling evidence for a retinal locus of iconic memory, there are several independent lines of evidence which suggest postretinal contributions to the icon as well. Furthermore, the literature on iconic memory is replete with anomalous findings and failures to replicate. Several investigators (e.g., Coltheart, 1980a,b; Long, 1980; Turvey, 1978) have recently argued that much of this widespread and unnecessary confusion has resulted from the use of nonequivalent experimental procedures for investigating iconic memory.

Another major shortcoming of research on iconic memory has been the explicit failure to concern itself with the perceived spatial attributes of stimuli, such as perceived depth, size, and distance, and their possibly significant role in the processing of information in iconic memory. With the exception of a few recent studies (e.g., Mustillo, Note 8; Mustillo and Komoda, Note 9), previous investigators of iconic memory have been exclusively concerned with simple manipulations of physical stimulus parameters, and accordingly, the proximal stimulus (i.e., retinal image) in investigating the underlying nature and degree of encoding of the information that can be represented in iconic memory. For example, in the previous studies that have found partial report superiorities with a variety of visual selection criteria (i.e., color, size, spatial location), the attribute denoted by the cue was manipulated in the physical display. Thus, differences in the critical attribute were represented in the proximal stimulus itself, and the selection of information from iconic memory may have been in terms of the retinotopic characteristics of the stimulus display. In that proximal stimulation does not adequately specify the properties of the distal situation, such manipulations provide little insight into the perceptual processes that may underly the selection of information from iconic memory. That is, they fail to provide any clear indication whether information in iconic memory is selected on the basis of the retinotopic or perceptual properties of the stimulus.

Rationale for the Present Empirical Study

Recently, Mustillo (Note 8) and Mustillo and Komoda (Note 9) reported some evidence which suggests that retinal disparity information may be processed within iconic memory. They found that observers in a partial report task could utilize, to some extent, the perceived spatial attributes of stereoscopic depth to selectively retrieve information from iconic memory. This finding implies that the information that can be represented in iconic memory is not solely retinotopic.

The present empirical study was conducted to assess the effectiveness of stereoscopically perceived size as a selection cue in Sperling's (1960) partial report paradigm. Perceived size was chosen as the variable of interest since its study provides a logical extension to the previous work of Mustillo (Note 8) and Mustillo and Komoda (Note 9). Furthermore, there are several psychophysical lines of evidence which indicate that the perceived size of a visual stimulus varies concomitantly with changes in retinal disparity. Lawson and Gulick (1970), Lawson, Gulick, and Park (1972), and Gulick and Lawson (1976) have repeatedly demonstrated that retinal disparity interacts with perceived size when retinal image size remains essentially constant. These investigators have shown that increasing crossed (positive) disparity makes a planar surface appear progressively closer and smaller to an observer. Conversely, increasing uncrossed (negative) disparity results in stimuli appearing progressively farther from the observer and larger. Analogous findings have also been reported recently in studies investigating the effects of depth separation on metacontrast masking (Fox and Lehmkuhle, Note 10; Lehmkuhle and Fox, 1980, Experiment 8). In all, the critical implication of these studies is that the perceived size of a stimulus cannot be determined on the basis of retinal image size alone. They also converge to suggest that there is a hierarchical analysis of stereo-spatial input such that the perception of perceived size results from the previous extraction and integration of perceived depth information.

In consideration of the findings that demonstrate that perceived size is directly related to retinal disparity, it does not seem unreasonable to posit that the basis of perceptual size processing may be postretinal. Indeed, there is some neurophysiological work by Blakemore, Garner, and Sweet (1972) that suggests that perceptual size scaling occurs as a result of processing at some postretinal stage or level in the visual system, perhaps in the inferotemporal cortex. This notion is also consistent with several findings which indicate that the size of human receptive fields, measured at the visual cortex, varies directly with the depth of visual stimuli (Marg and Adams, 1970), and that lesions in the inferotemporal cortex abolish the ability of monkeys to make discriminations of the actual size of objects, regardless of their distance in depth from the animal (Humphrey and Weiskrantz, 1969). Thus, the neurophysiological results of these studies, along with those indicating the existence of disparity-specific neurons in the visual system, support the idea that the mechanisms that are responsible for stereoscopic depth and size perception probably have a cortical, rather than a retinal or geniculate, neural locus.

Experimental Hypothesis and Predictions

The hypothesis being proposed here is that while the persistence of information in iconic memory may be generated retinally, as Sakitt's work suggests, the perception of stereoscopic depth and size must occur at some point in the visual system after the information from the two eyes has been combined. In essence, the hypothesis claims that there are postretinal components in iconic memory that cannot be accounted for simply in terms of retinal persistence.

In order to test this hypothesis, the present study investigated whether stereoscopically perceived size could be used as a selection cue for recall in iconic memory. Three stimulus conditions were set up where retinal and perceptual sources of size information were congruent (condition 1) or discrepant (conditions 2 and 3). In condition 1, the letters in two rows of a stimulus display were physically different in size; one row contained larger sized letters and the other row contained smaller sized letters, and both rows always appeared on the plane of fixation (no depth). In condition 2, both rows in the stimulus displays contained equally sized letters, and each row had a different depth value due to the introduction of retinal disparity. In condition 3, each row contained the larger or smaller sized letters. With the introduction of disparity in the appropriate direction, the letters were perceptually adjusted such that they had the same perceived size irrespective of the depth of the row.

Depending on the theoretical position that one adheres to, the three stimulus conditions predict three specific empirical outcomes. The retinal hypothesis of iconic memory (e.g., Sakitt, 1975, 1976a) would predict that retinal image size alone is the critical factor in the present experiment, whereas the postretinal interpretation being proposed here would predict that perceived size is also vitally important. The three idealized predicted outcomes according to both hypotheses are summarized and illustrated in Figure 1.

In condition 1 (Figure 1.1), both the retinal size and the perceived size hypothesis would predict identical outcomes, since the letters in the rows are not only retinally different but also perceptually different, and there is no disparity in the stimulus displays. Both hypotheses predict that cueing by size should result in a decaying partial report superiority. Ideally, since retinal and perceptual sources of size information are perfectly correlated, both hypotheses predict the same decay function. This stimulus condition also provides an opportunity to replicate von Wright's (1968) work. Von Wright demonstrated

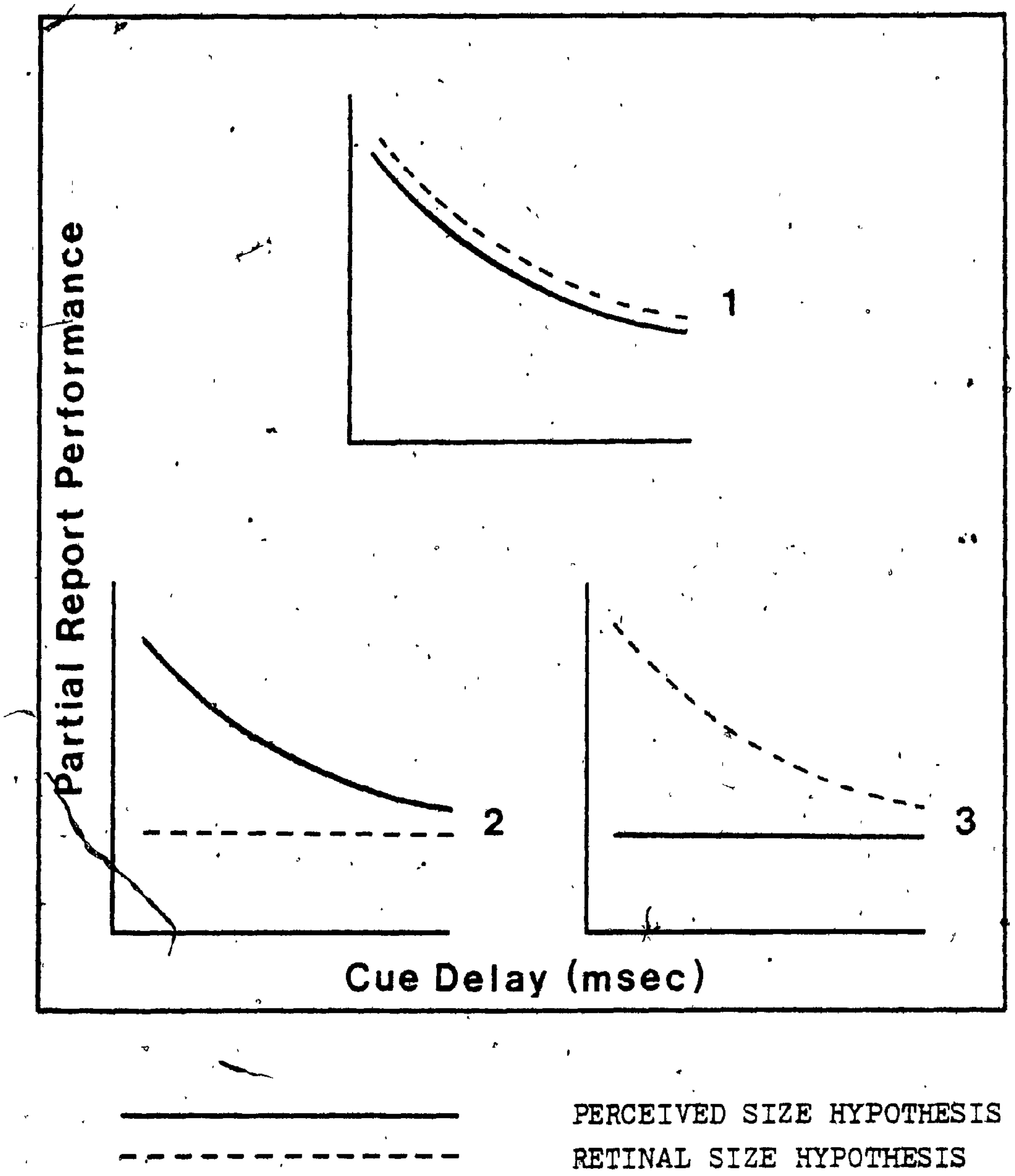

Figure 1. Idealized predictions according to a retinal and perceived size hypothesis.

that retinal size can be used as an efficient selection cue for recall in iconic memory. However, he only examined this with a 5-msec cue delay. In the present experiment, six cue delays were included to provide a more sensitive and reliable evaluation of the effectiveness of this selection cue.

In condition 2 (Figure 1.2), the retinal size hypothesis would predict no partial report superiority at any cue delay for the size cue because the retinal sizes of the letters in the two rows are identical. The perceived size hypothesis, on the other hand, would predict a typical partial report superiority effect that decreases as a function of increasing cue delay. Lawson and Gulick (1970) and Gulick and Lawson (1976) have shown that changes in perceived depth are invariably accompanied with changes in perceived size when the visual angle of a stimulus is constant. Thus, the occurrence of perceived depth in this condition will also result in differences in the perceived size of the letters since the visual angles are held constant.

In condition 3 (Figure 1.3), both hypotheses again generate different outcomes. The retinal size hypothesis would predict that since the letters in both rows are retinally different in size, observers should be able to use this stimulus attribute as an efficient selection cue for recall. Conversely, the perceived size hypothesis would predict that observers should not be able to effectively discriminate differences in the sizes of the letters since the letters are perceptually adjusted so that they appear identical in size, regardless of the depth of the row. Interestingly, the perceived size hypothesis predicts that if it is perceived size per se that is being used to select information from iconic memory, then the selection cue of size should exhibit no partial report superiority effect at any cue delay, even though the retinal sizes of the letters differ.

Method

Subjects. Six males and six females, ranging in age from 19 to 36 years, served as paid subjects. All had normal or corrected-to-normal visual acuity in both eyes, absence of any marked phoria, and adequate stereopsis and fusion, as assessed with a Keystone Ophthalmic Telebinocular. Stereoscopic acuity measures obtained with the Keystone Diagnostic Series (Aviators' Unit, D.C. 31 to D.C. 53) were equivalent to or better than 80 seconds of arc for each subject. All subjects were naive with respect to the purpose and design of the experiment, and none had previous experience with multielement tachistoscopic presentations.

Apparatus. The experimental viewing apparatus consisted of a four-channel dichoptic tachistoscope (two channels per eye), equipped with Mast/Keystone Telebinocular lenses. These achromatic lenses have a converging power of +5.0 D, and were mounted 5.3 cm apart horizontally. Placed immediately in front of the lenses were a pair of 50 x 50 mm beam splitters (one per eye) that served to superimpose the left and right eye fixation targets lying perpendicularly at either side of the subject's line of sight onto the center of the visual field. A sheet of opal glass (Edmund Scientific Co., Stock No. 2149) was mounted on filter holders in front of each viewing channel to produce a homogeneously illuminated visual field. All stimulus displays were rear illuminated through the opal glass and presented at an optical distance of 17.2 cm. The viewing apparatus is schematically illustrated in Figure 2.

The light sources on the viewing apparatus consisted of six 4-watt fluorescent lamps (Sylvania Corp., F4T5/CW) that were driven by a three-channel Scientific Prototype tachistoscope (Model GB) located in the same room as the viewing apparatus. Two such lamps, operating in parallel, lit the fixation channels, while the remaining four lamps operated in pairs to illuminate the two stimulus channels. The luminance of all channels, as measured at the eyepiece by a Spectra Brightness Spot Meter (Photo Research, Model UBD - $\frac{1}{2}$), was equated at approximately 28 cd/m^2. In addition, the luminance of the testing room was low enough

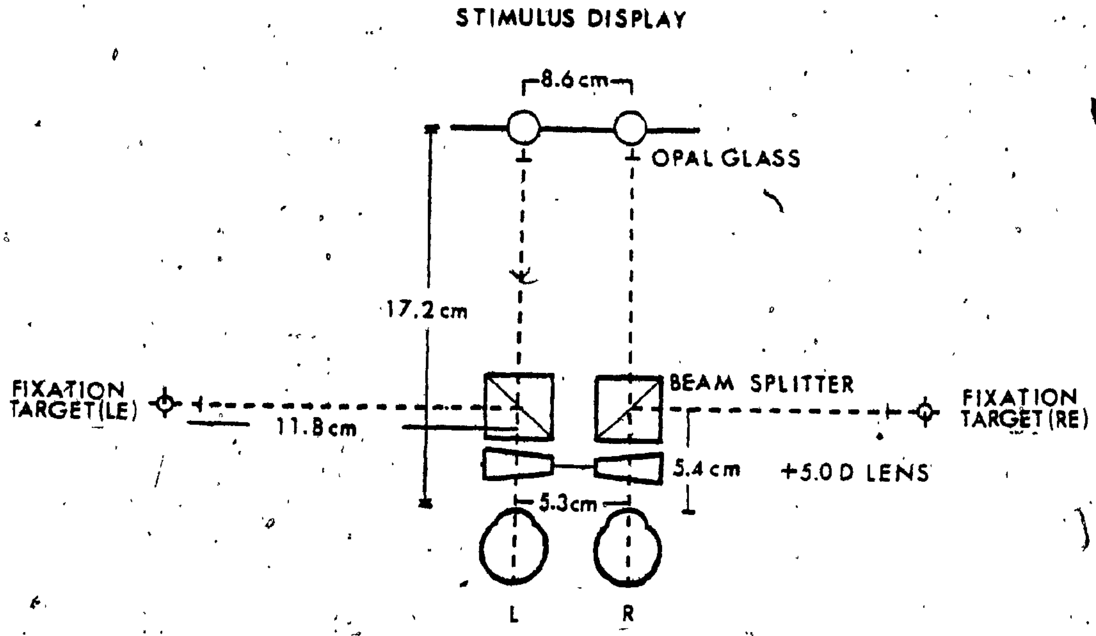

Figure 2. Schematic illustration of the experimental viewing apparatus. See the text for full details.

to necessitate the use of a small red light in order for the experimenter to record data between trials; its luminance was approximately 1.7 cd/m^2. This light was shielded from the subject and extinguished during trials.

A Digital Equipment Corporation PDP-11/34 laboratory computer controlled all the temporal parameters in the experiment (stimulus duration, tone duration, pre-exposure delay, cue delay), and generated the partial report cues. These cues consisted of a high, 2,000-Hz tone or a low, 500-Hz tone that were delivered to the subject via earphones. The computer was located in a room adjacent to the testing room.

Stimuli. The stimulus displays consisted of two rows of six randomly selected uppercase, consonant letters; the letter Y was the only consonant not used. The vowels and the letter Y were excluded to reduce the pronounceability of the letter sequences and to minimize the possibility of subjects' interpreting the letter arrays as words. No letter appeared more than once in the same stimulus display, and sufficient care was taken to ensure that visually similar letters did not appear in close spatial proximity of each other. A total of 120 stimulus displays were constructed for each of the three experimental conditions.

All displays were constructed with black, dry transfer letters (28 pt. Helvetica Light Letraset, No. 3023, for the larger sized letters; 24 pt. Helvetica Light Letraset, No. 3025, for the smaller sized letters). The original stimulus displays were photographed with Kodalith Ortho, Type 3, 35-mm film to produce white letter arrays on a black photographic background on the negatives, and reduced in size by a factor of four. They were subsequently mounted in pairs on black, flat-textured cards measuring 20.0 x 10.6 cm. Each stimulus display card had a pair of 2.54 cm-diameter holes punched 8.6 cm apart horizontally. These holes constituted the visual field to each eye, and the stimulus displays were always centered with respect to the entire visual field.

In condition 1, the stimulus displays always appeared on the plane of fixation, in the sense that there was no retinal disparity in the displays. Thus, each eye received identical stimulation. In condition 2, pairs of stimuli were constructed such that when viewed stereoscopically, one row of letters contained a crossed disparity of approximately 20 min of arc and the other row, an uncrossed disparity of 20 min of arc, relative to the plane of fixation. That is, depending on the direction of the disparity, one row of letters was perceived as being nearer and slightly smaller in size (crossed disparity), or farther and slightly larger in size (uncrossed disparity). In the case of condition 3, such manipulations in the stimulus displays made the letters in both rows appear the same in size.

The direction of the disparities within the stimulus displays in conditions 2 and 3 was always crossed with rows, so that one half of the displays contained a crossed disparity in the top row and the other half contained an uncrossed disparity in the top row. The magnitude of the disparity was held constant across both disparity conditions, and was within the limiting range of disparity values necessary for a patent stereopsis.[1]

In condition 1, stimulus displays were constructed such that one row contained the larger sized letters and the other row contained the smaller sized letters. In condition 2, the letters in both rows were identical in linear size, and were made to appear different in perceived size through an inequality in their disparities. In condition 3, the stimulus display dimensions were identical to those of condition 1, with the exception that the displays contained a retinal disparity. The retinal sizes of the letters in this condition were appropriately adjusted so that they had the same perceived size irrespective of the depth of the row.

After photographic reduction, each larger sized letter had a vertical and horizontal dimension of 1.975 mm and subtended approximately .66°. Each smaller sized letter had a vertical and horizontal physical dimension of 1.625 mm and subtended approximately .54° of visual angle. The entire larger sized and smaller sized letter arrays subtended a visual angle of 5.61° and 5.50° horizontal, respectively, and 1.53° vertical. (In condition 2, the vertical visual angle subtended by the rows was 1.65° or 1.42°, since both rows contained either the larger sized letters or the smaller sized letters). The separation between each larger sized letter was .33°, and between each smaller sized letter, about .45°. The spacing between the two rows of letters in the stimulus displays was .33° of visual angle, irrespective of the size of the letters in the rows. The visual field to each eye was circular and subtended 8.40° x 8.40° in diameter. The angle of convergence formed by the two eyes with respect to the stimulus displays was approximately 2.98°.[2] Representative examples of the stimulus displays used for each condition are shown in Figure 3.

The fixation target consisted of a binocularly fused 1.50°-diameter circle with corresponding monocular, vertical nonius lines. The nonius lines subtended a visual angle of approximately .75°. The fixation target was constructed to allow proper alignment of the upper and lower nonius lines seen inside the binocularly fused circle with the left and right eye, respectively. It also had accompanying

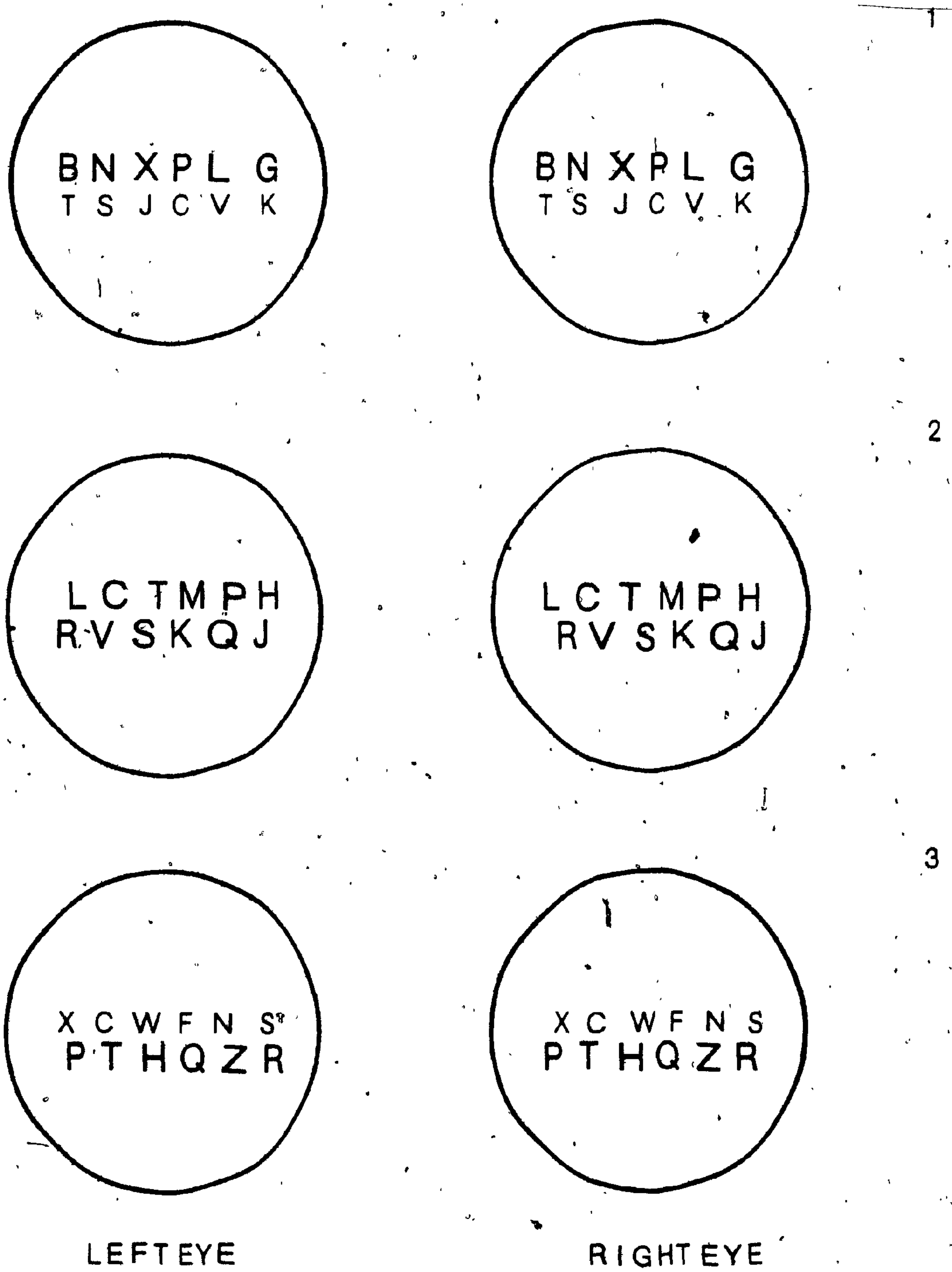

Figure 3. Representative examples of the stimulus displays used in each condition. Conditions 2 and 3 show displays which contain a crossed and uncrossed disparity in the top row, respectively. Stimulus dimensions have been enlarged by a factor of two for purposes of illustration.

.75° horizontal and vertical lines that were arranged 90° with respect to one another. The fixation target always appeared in the center of the stimulus displays, and covered approximately the entire vertical angular subtense of the two rows. Its basic configuration is illustrated in Figure 4.

Design. Subjects were tested individually in each stimulus condition following a repeated measures design. All subjects were required to complete three full sessions over a three-day period. Each session lasted approximately two and one half hours. Only one condition was run in each session, and only one session was run on each day. Stimulus conditions were presented to subjects in a completely counterbalanced order. The sequence of stimulus presentations and the order of cue delays and tones on partial report trials were randomly selected and recorded by a computer program, with the constraint that each possible combination appeared equally often across each session.

Procedure. There were two types of trials based on the type of report the subject was required to make. On whole report trials, no tone was presented at display onset, and the subjects were simply instructed to report aloud as many letters as possible from the entire stimulus display, independently of the size of the letters in the rows. All letters were to be reported in their correct

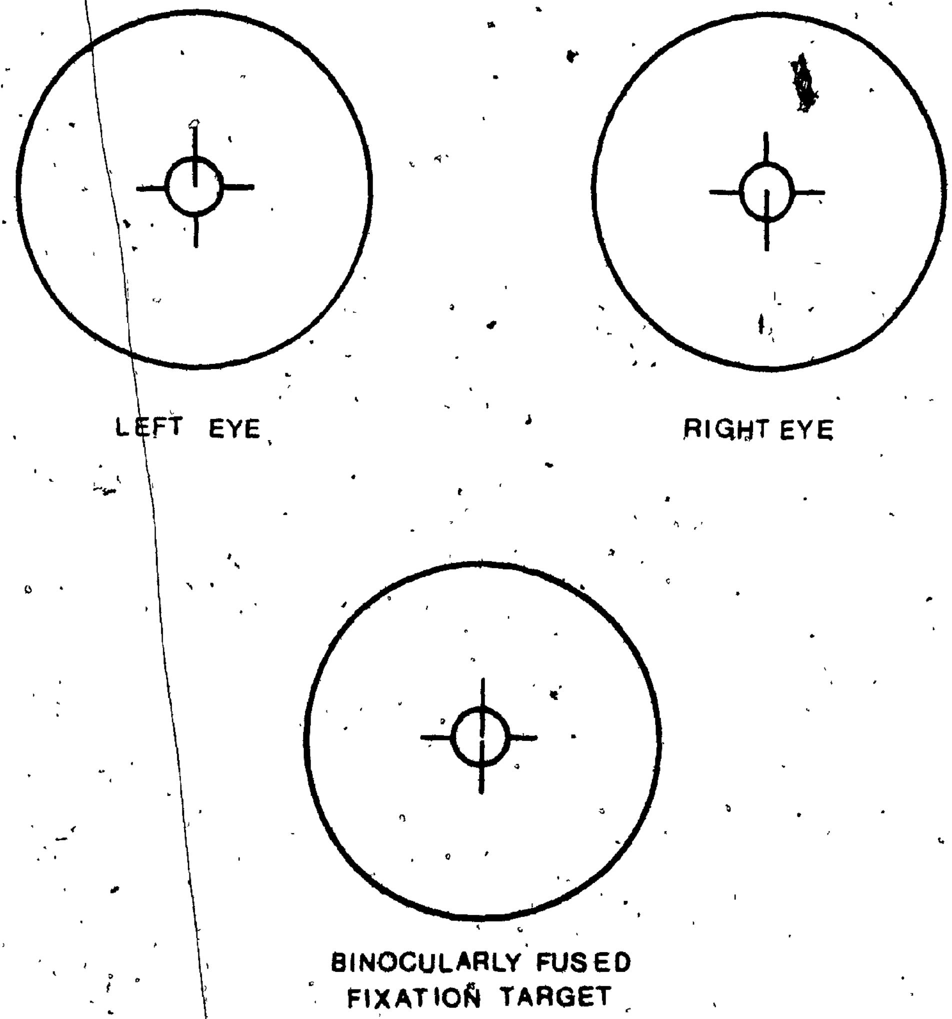

Figure 4. Basic configuration of the fixation targets viewed by each eye, and a representation of the binocularly fused fixation target with collinear, vertical nonius lines. Stimulus dimensions have been enlarged by a factor of two for purposes of illustration.

serial positions in order to be scored as correct. On these trials, the score for estimating the amount of information available to the subjects from a particular stimulus display was simply the number of letters recalled in their correct positions within the display.

On partial report trials, subjects were informed that a high or low tone of 50-msec duration would be sounded, and that this tone would come on either slightly before stimulus onset (-50 msec delay), at stimulus onset (0 msec delay), or at varying delays after the onset of the stimulus display (50, 150, 300, or 600 msec delays). If the high tone was presented, subjects were instructed to report aloud only those letters from a particular row that appeared smaller in perceived size; if the low tone was presented, they were instructed to report aloud only those letters from a particular row that appeared larger in perceived size. Subjects were requested to report the letters from the cued row in their correct serial positions as soon as possible after the presentation of the cue. They were instructed to report something on each trial, but not to engage in guessing. Partial report performance was assessed by multiplying the number of letters reported in their correct serial positions by two (since the subject only reported one half of the total stimulus letters) to obtain the estimated number of "letters available".[3]

In addition to reporting the letters on the partial report trials on the basis of their perceived size, subjects were also requested to furnish subjective size estimate reports. In conditions 1 and 2, they were simply asked whether the cued row of letters appeared larger or smaller in perceived size. In condition 3, they were asked whether the letters in the stimulus display appeared identical or different in perceived size. All such subjective size estimates were made after the subject had reported the letters from the cued row. All responses were recorded by the experimenter.

The rows were cued randomly with replacement so that on any given trial there was a .50 probability that a particular tone would be presented or that a particular row would be cued. Hence, there could be no advantage in cue anticipation. Cue delays were randomized within each block of partial report trials with the constraint that each cue delay was presented equally often. The size that was cued was completely counterbalanced across trials. Stimulus presentation duration was always 50 msec.

In each stimulus condition, each subject received a total of 320 trials; a block of 40 whole report trials immediately preceded and followed 10 blocks of 24 partial report trials. Within each block of partial report trials, each cue delay appeared four times, and each row was cued

12 times. Each subject received 20 trials for every combination of cue delay and row in each partial report condition. Although each stimulus display was randomly presented twice to each subject in each condition, previous research has effectively demonstrated that repetition of letter arrays affects neither the magnitude (Besner, Keating, Coke, and Maddigan, 1974; Merluzzi and Johnson, 1974) nor the rate of decline (Merluzzi and Johnson, 1974; Turvey, 1967) of partial report performance.

In any one session, the following general procedure was employed: Subjects dark adapted for about 15 minutes, during which time they were familiarized with the operation of the experimental viewing apparatus, informed about the nature of the stimuli and task for that particular condition, and given appropriate instructions concerning the interpretation of the partial report cues. Following these instructions, they were shown representative examples of the stimuli in question, and given sufficient practice in tone discrimination. Subjects then viewed the fixation target until the two vertical nonius lines seen inside the binocularly fused circle appeared collinear, thus ensuring correct initial vergence. When the fixation target was properly in focus, subjects self-initiated a trial by depressing a hand-held button. After a pre-exposure dark period of 500 msec, the fixation target was extinguished and the stimulus display was briefly exposed. Subjects were not informed on the nature of the upcoming trial, and no response feedback was given. The reappearance of the fixation target indicated readiness of the next trial. The interval between successive trials was approximately 30 seconds. Figure 5 shows the relationships among the temporal parameters used in the experiment.

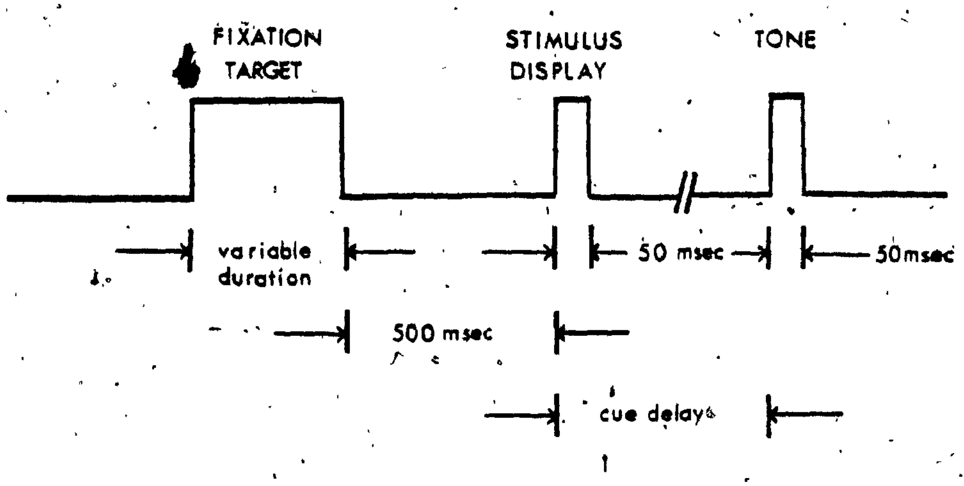

Figure 5. Relationships among the temporal parameters used in the experiment.

Results and Discussion

For each subject, whole and partial report performance (i.e., letters available) was computed on the basis of the number of letters that were reported correctly in their respective serial positions within the stimulus displays. Such estimates of subjects' performance were obtained for each condition.

Table 1 shows the mean number of letters available for report under each condition. In the computation of the results depicted in this table, the data for both the whole and partial report were averaged over all trials for each condition and collapsed across the 12 subjects. Given that the levels of performance on the whole report trials presented prior and subsequent to the partial report trials did not differ significantly, all $\underline{t}s(11) < -2.08$, $\underline{p} > .05$, the whole report data for the two blocks of trials were combined to obtain a single whole report score for each condition. Furthermore, as is evident from an inspection of the data in Table 1, the combined indices of whole report performance did not differ significantly across the three stimulus conditions, all $\underline{t}s(11) < -.75$, $\underline{p} > .20$.

The partial report data were also collapsed across blocks of trials for each condition and at each cue delay since the estimated mean number of letters available remained relatively constant for each subject when the

Table 1

Performance on the partial report in each condition as a function of cue delay, and on the whole report

Condition		Cue Delay (in msec)						
		-50	0	50	150	300	600	WR[a]
1	$\overline{X}$	9.33	8.38	7.22	6.15	5.46	4.74	4.29
	SD	1.84	1.89	1.85	1.84	1.81	1.78	0.90
2	$\overline{X}$	7.72	6.59	5.88	5.42	4.84	4.44	4.28
	SD	2.34	2.33	2.37	2.20	2.32	2.26	0.86
3	$\overline{X}$	5.61	4.94	4.48	4.22	4.13	4.06	4.26
	SD	2.33	2.26	2.18	2.15	2.11	2.09	0.91

Note. Maximum mean score = 12. Data are averaged across subjects. Each entry in the partial report is based on 480 trials; each entry in the whole report is based on 960 trials.

[a] WR refers to the whole report.

results of the first and last blocks of partial report trials in each condition were subjected to a Condition x Subject x Block analysis of variance, all Fs(9, 22) < 2.28, p >.05. This indicates that no apparent contributing practice trends were present. Additional analysis revealed that the subjects did not perform significantly better during the second presentation of the same stimulus displays, all Fs < 1. Thus, there were no significant indications of a repetition effect of stimulus display letters. As a result, partial report scores across each condition were combined.

A 3 x 6 analysis of variance with repeated measures was performed on the averaged partial report scores to evaluate the effects of stimulus condition and cue delay. The subject variable was treated as random, and the independent variables as fixed effects. The analysis of variance revealed that the main effects of stimulus condition, cue delay, and their interaction were significant beyond the .001 level (see Table 2). The significant interaction between stimulus condition and cue delay suggests different decay rates for the three conditions, and is evidenced from a visual inspection of the partial report results in Figure 6.

Results of post hoc comparisons between treatment means using Scheffé's procedure (Scheffé, 1953, 1959)

Table 2

Summary table of a two-way repeated measures analysis of variance on the averaged partial report results

Source	df Num	df Den	SS	MS	F
Condition (C)	2	22	192.08	96.04	252.74*
C x Subjects (S)	22		8.31	0.18	
Cue Delay (D)	5	55	250.36	50.07	625.88*
D x S	55		4.55	0.08	
C x D	10	110	43.74	4.37	72.83*
C x D x S	110		6.47	0.06	
S	11		6.97	0.63	

* $p < .001$.

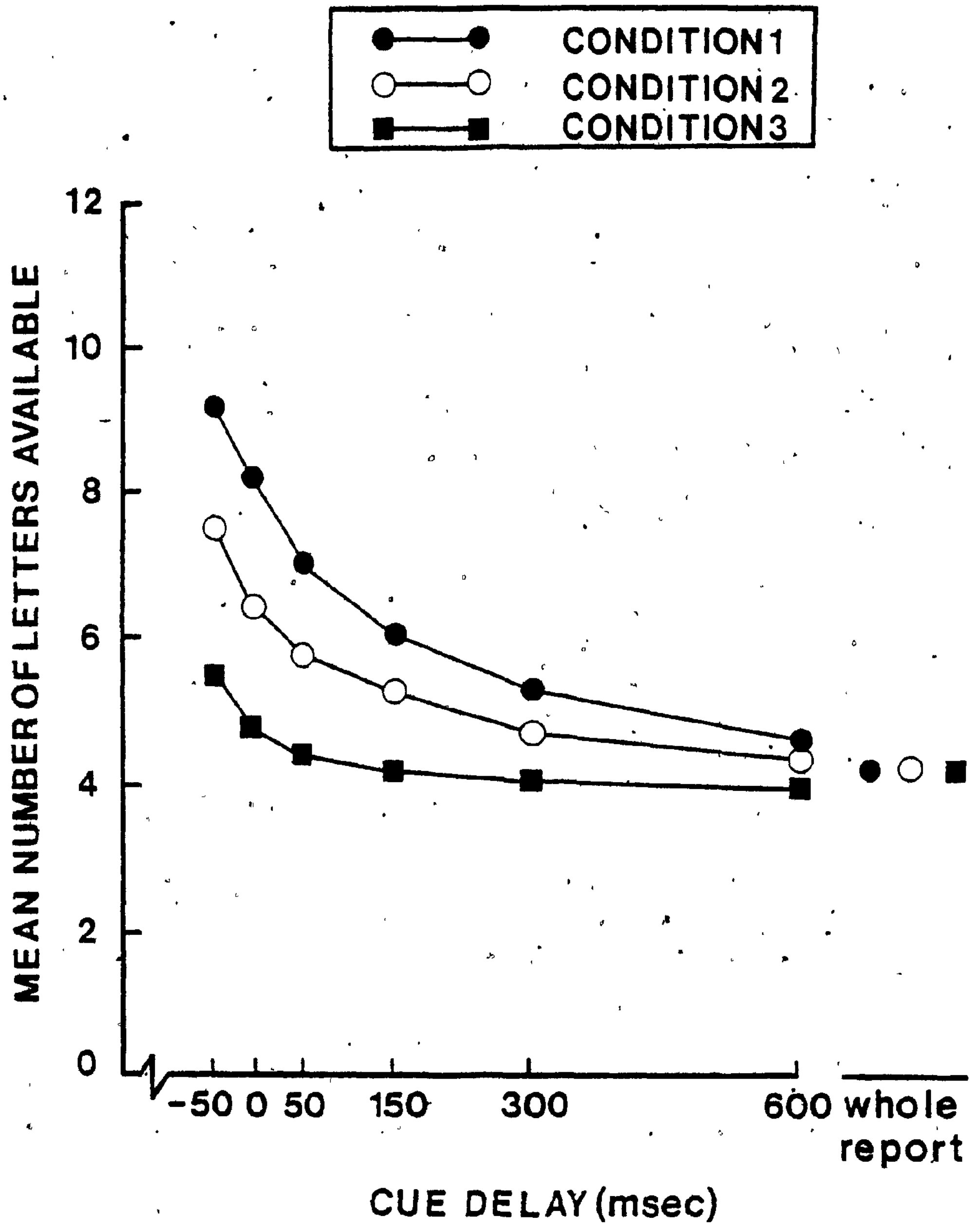

Figure 6. Estimated mean number of letters available in the partial report as a function of cue delay, and mean recall performance on the whole report. The data are collapsed across subjects.

indicated that partial report performance declined systematically with increasing cue delay at all cue delay intervals in conditions 1 and 2, all Fs(5, 55) > 16.33, $p < .05$.[4] The partial report data in condition 3, however, showed a significant decline in subjects' performance only at cue delay intervals between -50 and 50 msec, all Fs(5, 55) > 21.43, $p < .005$ (see Footnote 4). Beyond the cue delay of 50 msec, there was no evidence for additional significant decay of partial report performance.

Quantitative evidence for a partial report superiority for the selection cue of perceived size in each stimulus condition was evaluated by the use of multiple t tests with a corrected alpha level.[5] A superiority of partial report performance over whole report performance was observed at all six cue delays in condition 1, all ts(11) > 12.83, $p < .001$, at all cue delays in condition 2 except 600 msec, $t(11) = 3.14$, $p > .008$ (see Footnote 5), and was only evident at cue delays of -50, $t(11) = 7.22$, $p < .001$, and 0 msec, $t(11) = 5.48$, $p < .001$, in condition 3.

It is clear from the partial report results obtained in conditions 1 and 2 that the subjects did have information available to them shortly after the visual display was terminated that was not reflected in their whole report performances. Individual comparisons between the partial and whole report scores at all six cue delays in both conditions lend strong confirmation to this observation. It is also evident that information about perceived size was available to them but decayed with great rapidity as a function of increasing cue delay. The results of condition 3, on the other hand, indicate that there was little overall decline ~~in~~ partial report performance, and that the partial report only gave higher estimates of information availability than did the whole report when the cue came slightly before stimulus onset or at stimulus onset itself.

In all three conditions, there was a high degree of response compatibility between the cueing tones and the row of letters they indicated for report; subjects had no apparent difficulty in interpreting the auditory cues. They, nevertheless, committed three basic types of errors on partial report trials: (a) Subjects reported letters from the wrong row, (b) they reported no letters correctly from either row, or (c) they gave incorrect size estimate judgements following the report of the letters. Table 3 shows the percentage of these errors in each condition as a function of cue delay. The error data are collapsed across subjects for ease of exposition.

It is clear from the error summary analysis in Table 3 that the percentage of wrong-row reports and zero-correct errors that were committed by the subjects in each

Table 3

Percentage of errors committed in each condition as a function of cue delay

Condition	Type of Error	Cue Delay (in msec) -50	0	50	150	300	600
1	WR[a]	0.21	0.21	0.21	0.63	0.83	1.04
	ZC[b]	0.00	0.00	0.00	0.00	0.21	0.21
	SE[c]	0.00	0.00	0.00	0.00	0.00	0.00
2	WR	2.92	3.54	3.33	2.71	2.50	1.88
	ZC	0.00	0.21	1.67	3.13	5.83	6.57
	SE	7.50	7.92	5.83	3.75	3.13	2.08
3	WR	4.79	6.04	6.88	7.71	8.33	8.33
	ZC	0.42	1.04	2.50	2.29	2.92	3.75
	SE	62.92	60.63	55.42	54.17	47.71	49.58

Note. The data are collapsed across subjects. Each entry represents the percentage of errors based on 480 trials.

[a] WR refers to wrong-row reports.

[b] ZC refers to zero-correct errors.

[c] SE refers to size estimate errors.

condition were relatively small and did not vary systematically with increases in cue delay. Subjects made hardly any errors of these types in condition 1. In condition 2, they committed more errors, but the percentages of such errors did not exceed 7%. This suggests that the task in condition 2 was somewhat more difficult than that in condition 1. This may be due to the fact that stimulus displays in condition 2 contained a retinal disparity, whereas those in condition 1 did not.

The most interesting aspect of the error analysis, by far, concerns the large percentage of size estimate errors made by subjects in condition 3. It should be noted that in the instance of these errors, 50% correct must be considered chance performance level since subjects could make one of two possible responses; they could say that the letters in the stimulus displays appeared identical or different in perceived size. With the exception of one subject (subject C.C.), whose data will be examined shortly, every subject made a substantial amount of these errors in this condition, even though the occurrence of the other two types of errors remained comparatively small. This finding suggests that the task of discriminating the size of the letters in the two rows was very difficult when differences in the perceived size of the letters were minimized. This uncertainty in subjects' subjective estimates of size is amply apparent in the error analysis.

It is also very interesting to note that there were real individual differences among subjects in their ability to make correct size estimate judgements in condition 3. This may have been due to several reasons. It is possible that the perceived size of the letters may not have been appropriately equated for each subject. As a result, some subjects may have underestimated perceived size in the visual displays and based their selection on the retinal size of the letters. It is also conceivable that some subjects may have perceived real physical differences in the size of the letters. Finally, the possibility also exists that subjects may have processed the disparity information in the visual displays to different extents, and as a consequence, perceived size differences in the letters differently. Subject C.C. represents such an extreme case. Her overall results are depicted in Figure 7.

Subject C.C. reported that all the letters in the stimulus displays in condition 3 appeared different in perceived size, and committed no errors of any kind. Her data revealed a robust partial report superiority at each cue delay in each condition, accompanied with a significant decline in partial report performance with increasing cue delay. In fact, her partial report performance in conditions [illegible] and 3 did not differ significantly at any cue delay.

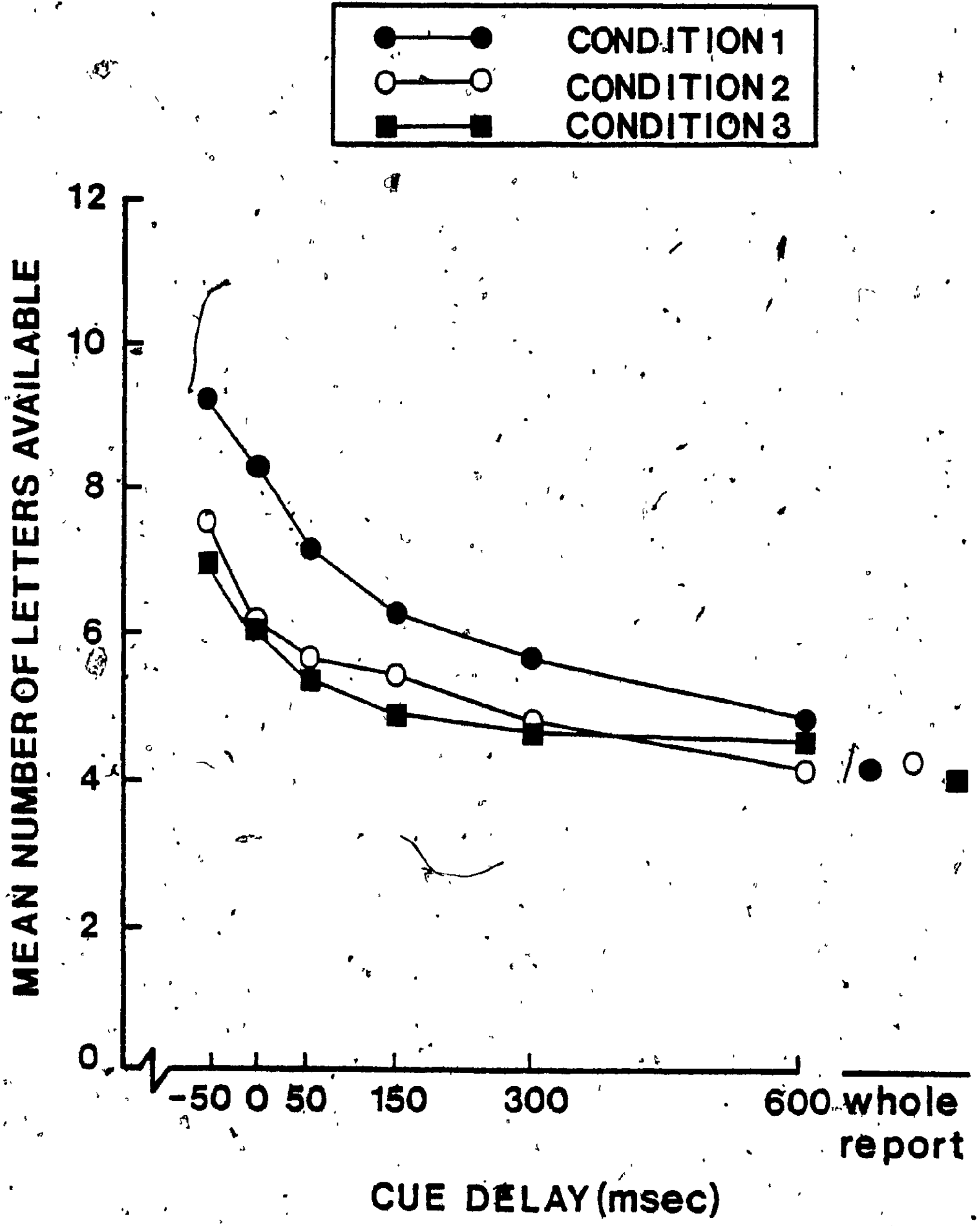

Figure 7. Estimated mean number of letters reported correctly under each condition by subject C.C. Each point in the partial-report represents the mean of 40 trials; each point in the whole report represents the mean of 80 trials.

all Fs(5, 195) < 1.19, p >.20 (Scheffé test). One can only speculate at present why this subject's partial report data are so discrepant with those of the other subjects.

In all, the results of the present experiment generally conform to the predictions that were derived from the perceived size hypothesis. The results of condition 1 replicate and extend von Wright's (1968) finding that size can be used as an efficient selection criterion for recall of information from iconic memory. The pattern of results in condition 2 indicates that when letters of constant angular subtense are made to appear different in size due to an inequality in their disparities, subjects can effectively retrieve information from iconic memory on the basis of the perceived size of the letters. The results of condition 3 demonstrate that when letters of unequal subtense are made to appear nearly identical in size, subjects perform predictably poorly when cued by size. This suggests that perceived size per se was being used to select information from iconic memory in this condition. The level of partial report performance in condition 3, however, is better than expected at the negative and short cue delays.

One possible interpretation of the present results is that the time that is required to process the dimension in the stimulus that is being used as the selection criterion determines the effectiveness of the selection process. It may be that perceived depth, and accordingly, perceived size, are processed within iconic memory but take an appreciable amount of time to develop. Given that the representation of information in the icon decays rapidly, subjects in condition 2 may not have had sufficient time during the brief existence of iconic memory to effectively process the selection cue and subsequently utilize it to retrieve the appropriate letters. According to this interpretation, partial report performance in condition 2 would be expected to be lower than that of condition 1 where there was no disparity information to process in the stimulus displays. The finding in the present experiment that subjects' partial report performance in condition 2 was consistently lower than their partial report performance in condition 1 at all six probed cue delays lends encouraging confirmation to this interpretation.

If this were the only factor involved, however, a simple transposition of the decay function in condition 2 along the temporal dimension onto the obtained decay function in condition 1 should be identical. Unfortunately, this does not occur. A simple transposition in time does not result in an adequate superimposition or overlap of the two decay functions. A close examination of the partial report results in Figure 6 indicates that the time constants in condition 2 appear to increase as cue delay is increased, suggesting that an interpretation based solely on the extra time it may take for stereoscopically perceived size to develop is not sufficient to satisfactorily account for the obtained results. Such a line of reasoning leads one to suspect that additional processes may be involved.

According to the perceived size hypothesis, it was predicted that the level of partial report performance in condition 3 should not have been significantly different from estimates derived from the whole report. Thus, subjects' partial report performance in this condition should have exhibited no significant decay or partial report superiority at any cue delay. The prediction was, to a fairly large extent, confirmed. Subjects showed a partial report superiority effect and an accompanying significant decline in partial report performance only at the shortest cue delays. It is possible that when the cue came early, subjects may have had enough time to effectively allocate their attention to the cue. When the cue arrived late, on the other hand, the iconic representation and clarity of the letters may have been sufficiently degraded as to make the discrimination of the size of the letters very difficult and time consuming. This interpretation is consistent with the observation that as cue delay was increased, subjects became very uncertain and began to report fewer letters from the cued row. In addition to reporting fewer letters in general, they also reported fewer letters correctly.

General Discussion

The results of the present study greatly corroborate and extend the previous findings of Mustillo (Note 8) and Mustillo and Komoda (Note 9). They indicate that it is possible to use partial report cues based on the spatial stimulus attributes of perceived size to select information from iconic memory. These results suggest that stereoscopic depth and size information can be processed within iconic memory, and imply that the information that can be represented within this early visual store is not solely retinotopic.

On the basis of the findings reported in this thesis, it is suggested that iconic memory should not only be defined in terms of the mechanisms of storage, but also in terms of the nature of the information it can contain and its interaction with subsequent stages or levels of visual information processing. Adoption of the idea that iconic memory may reflect an interaction of retinal and postretinal components allows for the empirical outcomes demonstrated in the present experiment, whereas an interpretation of iconic memory based exclusively on the persistence of photoreceptor activity (e.g., Sakitt, 1975, 1976a) implies that the present results should not have occurred. Accordingly, it is proposed that a multicomponent view may provide a more adequate theoretical conceptualization of iconic memory than is currently available.

There are several important questions, however, that are borne out of the present study that deserve to be examined in greater detail. The first concerns the finding that the selection of information from iconic memory on the basis of perceived size is more efficient than selection with perceived depth. Mustillo (Note 8) and Mustillo and Komoda (Note 9) previously found that their subjects could utilize information about the perceived depth of the letters in a stimulus display as a cue for recall from iconic memory. The magnitude of the partial report superiority effect they found for perceived depth, however, was much lower than that found in the present study for perceived size. This finding is somewhat puzzling since perceived depth and perceived size are intimately related to each other, and the perception of perceived size arises from the prior processing of perceived depth information (Gulick and Lawson, 1976; Lawson and Gulick, 1970).

It is possible that perceived size is a more salient selection cue than is perceived depth, one that can be more easily and readily associated with cueing tones in a partial report task. In the present experiment, subjects experienced no visibly-apparent difficulties in interpreting the tones and their relationships to the selection criterion (perceived size), whereas in the previous studies of

Mustillo (Note 8) and Mustillo and Komoda (Note 9), their subjects did encounter some cue interpretation difficulties. This occurred even though the same tones that were employed in the present experiment to cue perceived size were used to cue perceived depth in their studies. However, the difficulty may have been compounded in their studies because the same tones that they used to cue perceived depth in one condition were also used to cue spatial location in another condition. In the present study, the tones always cued the same stimulus attribute, namely, perceived size.

A further possibility for the differences in the magnitude of the obtained effects may be that separate input-analyzing mechanisms with different latencies underly the processing of stereoscopically perceived depth and size. Substantive empirical evidence for the existence of such mechanisms is, unfortunately, lacking at present.

Secondly, in condition 1, it was demonstrated that when perceived size is perfectly correlated with retinal image size, subjects can effectively select letters on the basis of their size. The present experiment, however, does not adequately address the question as to whether subjects in this condition based their selection on the perceived or retinal sizes of the letters in the stimulus displays. It is possible that subjects in this condition may have selected the letters on the basis of either stimulus dimension. Further quantitative investigation is needed in order to determine the exact contribution of each.

A third question that is raised by this experiment concerns the possible confounding influence of having the selection criterion of perceived size completely crossed with rows of letters. In this study, subjects reported the letters from a particular row that appeared to be larger or smaller in perceived size. It is possible that some subjects may have utilized stereotyped scanning strategies for processing the information in the displays. For example, they may have had enough time to examine the first letter in a row and subsequently report the rest of the letters in that row if it was the correct row, or switch to the other row if it was the incorrect row. Such viewing strategies may have influenced the amount and degree of information processing in the present experimental situation.

It would be valuable for future research concerned with this question to examine whether partial report superiorities with the selection cues of perceived depth and size can be obtained under different stimulus conditions where possible subject-scanning strategies are controlled. One such possible avenue of investigation could be to use a circular stimulus display and cue letters or digits randomly by perceived depth and size independently of spatial location. If a robust partial report superiority effect is obtained with such a stimulus display configuration, this would greatly strengthen the idea that the spatial stimulus attributes of perceived depth and size can be used as efficient selection cues in iconic memory.

Another question that urgently deserves to be addressed concerns the temporal course for the development of stereoscopic depth and size perception. It is known, for example, that stereoscopic depth perception of random-dot stereograms requires about 50 msec to develop (Julesz, 1964; Uttal et al., 1975).

Quantitative research relevant to this issue in other experimental situations is presently not available. It would be very useful to determine the time it takes for perceived depth and perceived size to develop in discrete stereoscopic stimulus displays, since the processing of stereoscopic contours in random-dot stereograms may involve a different mechanism than processing such contours in a discrete stereoscopic situation. This could be accomplished, for example, with a reaction time study where subjects would be required to respond as quickly as possible to perceived depth and perceived size differences in a stereoscopic array of dots.

Finally, it could be argued that while the findings of Mustillo (Note 8), Mustillo and Komoda (Note 9), and the present study suggest that subjects can utilize the stimulus attributes of perceived depth and perceived size to selectively retrieve information from iconic memory, they do not necessarily imply that these perceptual variables must be processed within iconic memory. It could be the case that perceived depth and size are processed outside iconic memory.

The present suggestion that iconic memory may reflect postretinal involvement requires additional empirical support. Triesman et al. (1975), for example, were able to claim a postretinal locus for iconic memory for movement information because retinal persistence cannot signal motion. One way to strengthen the claim that iconic memory also involves postretinal contributions could be to have an array of dots moving individually toward or away from the subject in depth. The subject would be required to report the direction of motion in depth for the cued row.

In conclusion, it is seriously suggested that future research should be designed to assess further the perceived spatial properties and characteristics of iconic memory. Such research may not only help to clarify the ambiguity and uncertainty that still plague the study of iconic memory, but may also help to increase present knowledge about any interactions between the processes that may underly human pattern recognition and visual space analysis.

Footnotes

[1] The binocular disparities in the stimulus displays were within the limiting range of disparities for a patent stereopsis, where "the disparities range from about 10 minutes of arc at the maculas to 70 minutes of arc at a peripheral angle of 6 arc degrees" (Ogle, 1952, p. 259). As long as the disparities are within this region, the disparate points will be seen as a single fused image in depth.

[2] The angle of convergence formed by the two eyes with respect to the stimulus displays was calculated by the following formula:

$$\gamma \text{ (in degrees)} = 57.3\left(\frac{0.065}{D}\right) \qquad (1)$$

"where D is the [virtual] distance to the fixated object in meters. The values of 57.3 and 0.065 represent a trigonometrical constant and the average interpupillary distance, respectively" (Gulick and Lawson, 1976, p. 251).

[3] In a typical partial report paradigm, "when N letters are presented and j are called for, the estimated number of 'letters available' is given by $\hat{A} = \hat{S}\ (N/j)$, where $\hat{S}$ is the number of letters reported in their correct serial positions for the response of length j. This calculation assumes that

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