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ON THE INDEPENDENCE OF LOCATION AND IDENTITY
INFORMATION IN ICONIC MEMORY

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Joseph Spencer Brown

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M.S. degree in Psychology

David E. Irwin
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ON THE INDEPENDENCE OF LOCATION AND IDENTITY INFORMATION IN ICONIC MEMORY

By

Joseph Spencer Brown

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ABSTRACT

ON THE INDEPENDENCE OF LOCATION AND IDENTITY

INFORMATION IN ICONIC MEMORY

By

Joseph Spencer Brown

Most contemporary models of iconic memory assume that location and identity information are coded separately rather than together. This assumption is questionable given the small number of contradictory studies upon which it is based. Three experiments were conducted to examine this contention. Experiments one and two used a recognition test to show that location and identity information are stored as an integral unit. It was suggested that the recognition memory test that was used is more sensitive than previously employed measures to the actual contents of the icon. In experiment three, pseudo-letter stimuli were used to investigate the nature of the representation of identity and location. It was found that the representation more closely resembles an image than an abstract store. Implications for models of iconic memory are discussed.

To my mother and father,

with all my love and gratitude

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TABLE OF CONTENTS

LIST OF FIGURES

Figure | Page

INTRODUCTION

The systematic study of iconic memory began with the work of George Sperling (1960). In these experiments, Sperling introduced the partial report technique in hopes of examining the introspection of subjects in visual experiments, that they saw more than they could report (Bridgin, 1933; Wilcocks, 1925, reported in Sperling, 1960). The logic of these experiments was that if subjects were asked to report only part of a stimulus array, but didn't know what part they would be asked to report until the array was no longer available, then an estimate of the number of items actually available for report could be obtained by multiplying the percent of the letters correctly reported by the number of letters in the array.

To begin his examination of the phenomenon, Sperling first determined the number of letters that subjects could report from an array if asked to report the whole array. At exposure durations of up to 500 msecs, subjects were able to report roughly 4.5 items (though there was considerable individual variation). He then compared this to the number of items that were "available" for report, that is, the proportion of items that subjects could report if only asked to report three or four items. Subjects had considerably more items available than could be reported, for up to 500 msecs after stimulus offset. Further, Sperling found that the availability of these letters was disrupted by the presentation of a bright post exposure field. The final experiments of this seminal work demonstrated the precategorical nature of the phenomenon that would later become known as iconic memory. This was done by asking subjects to report either all the letters or all the numbers in an array containing both. Subjects were unable to report items based on the category of the item at levels higher than whole report performance.

These experiments led Sperling to believe that there exists an image after stimulus offset that allows subjects to act on the image as if the array were still present. This conclusion, along with the others derived from these experiments, led to the formulation of what has been referred to as the "classic" definition of iconic memory (Irwin and Yeomans,1986a; Yeomans and Irwin,1985), that is, as a precategorical, maskable, short-lived, visible image.

Consistent with the notion that the icon is visible, Sperling, in the discussion of these experiments, implied that experiments that measure iconic memory by means of estimating the subjective duration of flashes of light are comparable to the partial report paradigm.

Following this logic, Sperling (1967) ran an experiment in which he asked subjects to adjust an auditory "click" to correspond to the onset or offset of visually presented stimuli. Though he reports little of his data, this paradigm was adopted by Ralph Haber and Lionel Standing (1970) to examine the subjective duration of visual stimuli. In this experiment, subjects were asked to adjust "clicks" to correspond to the onset or offset of stimuli as the duration of the stimuli and the type of pre and post exposure field were varied. Defining visual persistence as the difference between the interval between the two "clicks" and the actual exposure duration of the stimulus, Haber and Standing found that visible persistence decreased as exposure duration increased. Further, visible persistence could be ended with a noise mask or a very bright post exposure field. Using essentially the same procedure as that used by Haber and Standing, Robert Efron (1970) determined that, in addition to being an inverse function of stimulus duration, the duration of visible persistence is an inverse function of the intensity of the stimulus when intensity was under 3.4 ft/lumens. Thus, by means of similar experiments (Bowen, Pola, and Matin, 1974), and more objective experiments utilizing integration of pairs of stimuli (DiLollo, 1978,1980; Eriksen and Collins, 1967) the consistent view of iconic storage began to take shape.

Since virtually no finding in psychology goes unchallenged, it is not surprising that the inverse relation between intensity and visible persistence is not universally accepted. For instance, Long and Beaton (1980,1982) found positive effects of stimulus intensity on the duration of visual persistence using techniques similar to those of Haber and Standing. On closer examination, it becomes apparent that Long and Beaton's results were caused by the very high intensities that they used, ranging from 1 to 30 ft/lumens. It is not unreasonable to assume that these high intensities lead to afterimages and thus are not measuring the same effects as other investigators. Given this criticism, the traditional view of iconic memory seems relatively safe from attack from this quarter (for a more detailed review of Long's work, see Irwin and Yeomans ,1986b).

Unfortunately for the classical model of iconic memory, it is almost certain that the assumption that the same underlying visual store is measured by both tests of visual persistence and the partial report task measure is not correct. This can be seen by contrasting the effects of duration and intensity on the estimation of visual persistence with their effects on performance on the partial report task. Adelson and Jonides (1980) examined the effects of intensity on performance on a partial report task. Using intensities ranging from 8.7 mL to 70 mL, they found that though the overall level of accuracy could be affected by stimulus intensity, the decay function of the partial report task was the same at all levels of illumination. Further, the effect of stimulus intensity on the overall level of performance was to make performance worse as intensity decreased . Thus, if variations of intensity affect the partial report task at all, it is not by making the information last longer at lower luminances, as might be expected from the duration judgments of the experiments discussed earlier, but instead, by making the information less clear initially.

In addition to the discrepancy between the effects of luminance in partial report tasks and duration judgments, the effect of stimulus duration in partial report tasks and duration judgments indicates that the two measures are, in fact measuring different underlying perceptual processes. Recall that perceived duration measures find a negative effect of stimulus duration, however, in a partial report task, either no effect (Sperling 1960) or a positive effect is found. The best evidence for this contention is found in the work of David Irwin and Jim Yeomans (Yeomans and Irwin, 1985; Irwin and Yeomans,1986; Irwin and Brown, in press). For example, in a partial report task in which the stimuli were three by three arrays of letters, and the subject's task was to report a single row indicated by a probe, stimulus durations ranging from 50 to 500 msecs had a positive effect on partial report performance. This adds more support to the argument that iconic memory is something more than simply a visible trace of the original stimulus.

Max Coltheart (1980), upon reviewing this evidence and much more, in what he referred to as an exhausting review, concluded that there are at least three logically independent elements of what was being studied under the rubric of iconic memory. The first of these elements is the neural persistence in the visual pathway after stimulus offset. The second element is visible persistence, defined by the subjective experience of the subject that the stimulus is still present after offset. Finally, there is informational persistence, which is the availability of visual information after stimulus offset. This is logically independent of visible persistence, since you need not actually see the stimulus to remember what it looked like.

In addition to the logical independence of these three elements, there is substantial evidence that at least the last two are substantially independent in an empirical sense. That is, as described above, there are different effects of duration and intensity on the two types of phenomena. The partial report task only requires knowledge of the visual characteristics of the array, since a location probe is used to cue report, and this task finds positive effects of duration and intensity, while the duration judgment measures the visible duration of the stimulus and is affected negatively by increasing duration and intensity of the stimulus. Based on the original definition of iconic memory by Neisser (1967), Coltheart concludes that it is the measurement of informational persistence as measured by partial report tasks that is the true domain of the student of iconic memory (though this in no way should be taken to denigrate the study of visible persistence). Accordingly, in this discussion, I will use the term iconic memory to describe Coltheart's informational persistence.

Coltheart goes on to argue that, in addition to being non-visible, iconic memory does not behave as you would expect an image to behave. That is, instead of decaying slowly away like a photographic negative exposed to light, it appears that different visual aspects of the information found in the iconic store decay at different rates. Specifically, position information seems to decay more rapidly than identity information. In support of this contention, he cites work by Townsend (1973) (see also Dick,1969; DiLollo,1978).

Townsend performed a series of experiments that explored the relation of location and identity in the icon. The first of these experiments, a variation of the standard partial report paradigm, included an analysis of errors of intrusion, that is, errors in which the subject responded by naming a letter not contained in the stimulus array. Townsend pointed out that these errors occurred at much lower frequencies than might be expected if iconic memory were simply a decaying image. Though she doesn't point it out directly, it is apparent that the remaining errors, those in which the letter named by the subject was in the array, but was not in the position probed, occurred at higher levels than predicted by a decaying image. This suggested to Townsend that location might be stored separately from identity, and that location information decays more quickly.

In a second experiment, Townsend asked subjects to indicate whether or not a probe letter had appeared in the stimulus array. In this task, there was no effect of cue delay. Townsend suggested that in tasks of this kind subjects needed only identity information, and therefore no delay effect was found because identity information did not decay in iconic memory. She concluded that the decline in partial report performance was the result of loss of spatial information about the elements of the stimulus array.

While Townsend's results have been replicated by a number of people (Yeomans and Irwin, 1985; Irwin and Yeomans,1986; Irwin and Brown, in press; Mewhort, Campbell, Marchetti and Campbell, 1981; Mewhort, Marchetti, Gurnsey and Campbell, 1984), there are at least two problems that suggest caution. First, there is at least one alternative explanation for the results of the first experiment; it is possible that when subjects did not know what item had appeared at the probed location, they simply chose an item at random from the set of items that they could remember. Such a stategy would result in more location errors than intrusion errors. This is a quite reasonable strategy given that there are far more possible items that are not contained in the array than are contained in the array. It might seem to the subject that the best chance of responding correctly is to assume that they had mislocated an item, and therefore they should guess from the subset of letters that they were sure were in the array. This criticism might seem quite weak were there converging evidence supporting Townsend's conclusion, however, as we shall see, the literature is far from clear on this point.

The second of Townsend's experiments is also flawed. In this experiment, in which subjects were asked to indicate whether a probe letter was in the stimulus array, it seems clear that there should be no partial report advantage and therefore no decline of accuracy with cue delay, regardless of the nature of the icon. If the partial report advantage occurs because of preferential processing of parts of the icon, then we would expect no decay over time, because each item of the array would have to be processed in order to compare it with the probe. Therefore, the response of the subject would be based on the information that could be processed during the life of the icon, just like full report. Thus, the lack of decline in performance with increasing cue delays only shows that if the subject's response requires the same type of information as full report, it, like full report, does not decay with time.

In addition to Townsend's investigation, there have been only a few systematic attempts to investigate the decay of identity and location specifically in iconic memory. The first of these, Ken Den Heyer (1972), draws the conclusion that location and identity are coded together, and decay at the same rate. To do this, den Heyer employed Garner and Morton's

(1969) procedure for testing perceptual independence. Garner and Morton's procedure requires three tasks: processing both identity and location simultaneously; processing identity or location alone in the presence of both types of information; processing identity or location information without the presence of the other type of information. To accomplish these conditions, den Heyer used three different type of stimuli: the first consisted of three 2x4 matrices with letters occupying three of the eight positions in each array; the second type consisted of three 2x4 matrices with a circle placed at three of the eight possible positions in each matrix; the third type consisted of a 3x3 matrix filled with lettters. Each type of stimulus was briefly displayed and followed at various delays by a probe indicating which of the three matrices to report (type one and two) or which column of letters to report (type three). The type of report varied; for the first type of stimuli, in which both identity and location information were present, subjects were asked to report: 1) only the identity of the three letters in the cued matrix; 2) only the locations of the three letters; or 3) both the location and identity of the three letters. With stimuli of the second type, in which only location information was present, subjects were asked to report the locations of the three O's. With the third type of stimuli, in which only identity was supposed to be present, subjects were asked to name the three letters in the column indicated by the probe in any order. Using this procedure, den Heyer concluded that identity and location were coded together and decayed at the same rate. He did, however, allow that the decay of location information might have a greater effect on performance than decay of identity.

Unfortunately, there is at least one major flaw in den Heyer's study. To see this, consider the type of location information that is required in the conditions in which only location information is to be reported. In this case, rather than reporting location information about specific letters, subjects are asked to report what is essentially the pattern of the array. This is very different than the kind of location information examined by Townsend (1973). To see this we need only examine the work of Phillips (1974) who found that subjects can make same/different judgments about dot patterns at levels above chance for delays of up to nine seconds, long after the icon has decayed away. Therefore, it seems apparent that den Heyer's "location only" conditions are very different from locating a specific item within an array.

A much more recent study of the decay of location and identity in the icon by Chow (1986) manages to further muddy the water by drawing the only conclusion that could possibly disagree with both of the previous studies. That is, Chow concluded that, as Townsend contended, location and identity are stored separately, but that identity decays *more* quickly than location information.

In Chow's experiments, he attempted to take advantage of the predictions independence of identity and location make about the conditional probability of correct localization given correct identification and of correct identification given correct localization. To do this, he took the strong position that the decline in partial report performance is almost exclusively the result of the loss of location information from iconic memory (as do Mewhort, Campbell, Marchetti and Campell;1981). If this assumption is made, the conditional probability of correct identification of an item of the array, given correct localization of the item (P(I/L)), should be constant with increasing ISI, since identity information is not decaying as location information decays. Further, the conditional probability of correct localization given correct identification (P(L/I)) should decline with ISI.

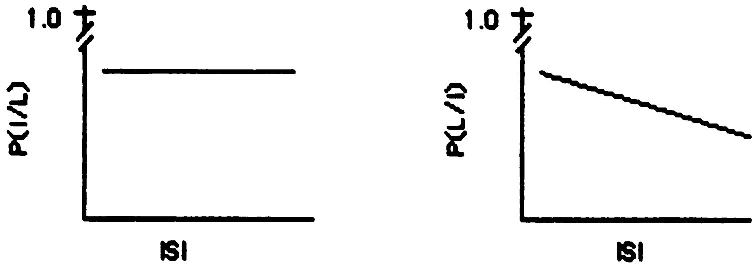

Figure 1. Chow's predictions based on fast decay of location information.

Chow's task consisted of presenting subjects with a seven letter array followed at various intervals by a probe indicating what position in the array the subject should report. The subject was asked to name the item indicated by the probe and its position. Chow found that the probability of reporting the location correctly, given the correct reporting of identity (P(L/I)) was constant across ISI, while the probability of reporting the correct identity given correct reporting of location (P(I/L)) declined with ISI. This is in direct opposition to the predictions based on the rapid and independent decay of location information. Chow concludes that the decline in partial report performance with increasing cue delay is caused by the decay of identity information rather than location information.

As in the studies described above, Chow's conclusions are subject to criticisms that suggest great caution in accepting this as the definitive answer to the independence issue. The main criticism is that while Chow assumed that the location judgments of subjects were a direct assessment of their knowledge about the location of the letters in the array, they were in fact only a measure of their ability to localize the probe. That is, the subject obviously believes the letter they are reporting occupied the position indicated by the probe, therefore, all they need do is report the letter's identity and then the position of the probe. Given this interpretation, it is not surprising that P(L/I) did not decline with ISI, since the probe was presented at the end of each ISI. It is not surprising that, given a familiar display, subjects could tell you the position of the probe no matter how long the delay. Further, to correctly identify the letter in the array, you must either have correctly localized the probe, or have mislocalized both the probe and the letter. Since the mislocation of both probe and letter to the same position should be quite rare, P(L/I) must be quite high, since to correctly identify the letter you must know the probe's position. In the same way, it is not surprising that P(I/L) declined with ISI. This decline could be the result of either a decline in identity information as Chow concludes, or a decline in information about the location of the elements of the array that is independent of ability to localize the probe. If you know the location of the probe, but the positions of array items have decayed, you will not be able to correctly name the item indicated by the probe, thus the decline.

It is obvious that the nature of the storage of identity and location in iconic memory is far from clear. It is possible that this confusion exists because the recall measures, such as partial report, which are the primary source of data in these studies, are simply not suited for the task at hand. A potential problem with these procedures is that instructions to report the letter indicated by the probe may encourage subjects to devote more attention to retaining the identity of the letters at the expense of their location. Further, given that subjects undoubtedly have much more experience with overlearned letter identity codes than with the location codes associated with a particular experimental stimulus configuration, it may not be too surprising that identity information often appears to be more durable than location information. Thus, the contradictory evidence found above may be the result of encoding, retrieval or response biases which differ across experiments, rather than differences in the amount of information actually contained in iconic memory.

Even in studies especially designed to examine naming and locating in briefly presented displays, the independence of location and identity information is far from clear. For instance, Krumhansl and Thomas (1976) found that accuracy for identifying a single letter was independent of accuracy for locating that letter in absolute space, but the same investigators found that identification and localization were not independent when multiple letters were used (Krumhansl,1977, Krumhansl & Thomas, 1976; 1977). It is important to note that since these investigators were not interested specifically in iconic memory, they presented a mask imediately after stimulus offset and asked subjects to delay responses for 500-1000 msecs, thus it is quite possible that relatively little can be learned about iconic memory, which decays considerably in the first 500 msecs and is severely disrupted by masking in the first 150 to 200 msecs after offset (Irwin and Yeomans, 1986a). Logan (1975), in a visual search paradigm, found that the presence of distractors interfered with locating a target, but had no effect on naming it, suggesting that identification and localization are independent. Here too, however, iconic memory was not specifically at issue, so masks were presented immediately after stimulus offset. Thus, at best this information bears on the extraction of information from the icon before its destruction, rather than the nature of information storage within the icon itself.

Given the vexed nature of the field, it is somewhat surprising that all three of the most explicit models of iconic memory now in use all rely to varying degrees on the assumption that location information decays more quickly than identity information in iconic memory. Before describing our attempts to disentangle the problems associated with previous experiments, let's first examine these theories and their reliance on this shaky assumption.

The first of these theories is the dual buffer model of Mewhort, Campbell, Marchetti and Campbell (1981; Mewhort, Marchetti, Gurnsey and Campbell, 1984). This theory argues that iconic memory consists of two distinct stages, the first being a precategorical, duration dependent store of feature level information about the stimulus; the second stage is a character buffer that contains the identified elements of the array and their relative spatial positions. In the second store, location information is more fragile than identity information, that is, it decays faster and is more vulnerable to masking. Thus, Mewhort et al argue that masking affects the two stores quite differently. The disruption caused by masking in the first store results in the disruption of feature level information, and thus errors in identification, the identification errors discussed earlier. Masking during the duration of the second buffer results only in errors of location. Among other things, this distinction between feature and character buffers allows Mewhort et al to account for the high number of location errors relative to intrusion errors found in virtually all partial report tasks by arguing that these errors are the result of decay of location information in the character buffer. Thus, the dual buffer model "...makes a strong distinction between spatial and identity information..." (Mewhort et al, 1981, p. 52).

The second major model of iconic memory which makes the assumption of independence of location and identity information was proposed by Irwin and Yeomans (1986a; Yeomans and Irwin, 1985). Like Mewhort et al, they propose that iconic memory consists of two stages. The first stage consists of a visual storage which contains a visual analog of the stimulus and lasts 150 to 300 msecs after stimulus offset, independent of stimulus duration. The visual store is vulnerable to masking. The second stage of the model is an abstract coding of the identity of the elements of the array, paired with an imprecise and/or quickly decaying coding of location information. This store is held to be invulnerable to masking. As you can see, this model bears a great deal of resemblance to Mewhort's model, especially in regards to the treatment of identity and location information. The main differences lie in predictions about the effects of stimulus duration on the duration of the first stage of processing and the predictions about the second stage's vulnerability to masking.

The final model of iconic memory that should be included was recently proposed by Peter Dixon (1986). This model, also a two stage model, was proposed to account for an unusual configuration of data found in a verification task in which subjects were asked if a probed letter was in a stimulus array. Very different results were found on present trials (in which the probe was in the array) than absent trials (the probe was not in the array). Trials with short positive SOA's showed a decrement in performance in the absent trials, but not in the present trials, relative to negative and long positive SOA's, as shown in figure 2.

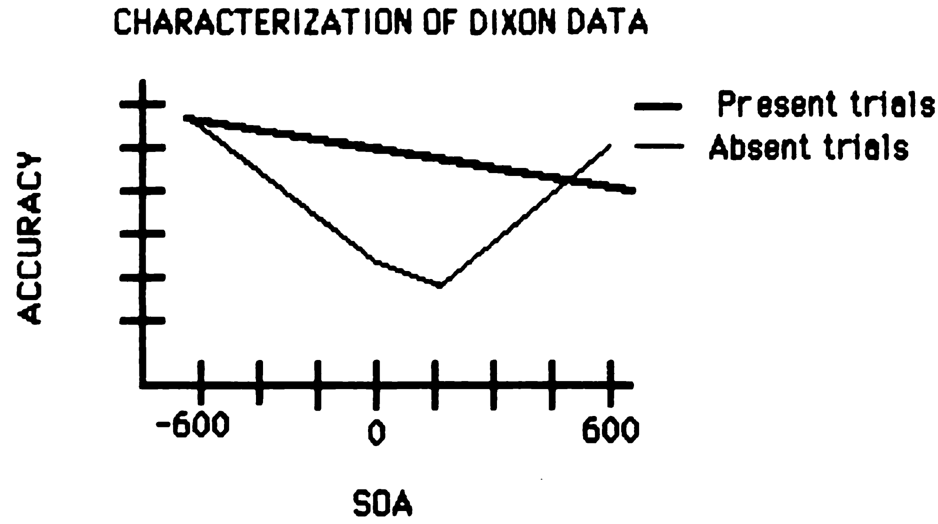

Figure 2. Characterization of Dixon's data.

Though Dixon also proposed a dual buffer model, this model differed substantially from the dual buffers proposed by Irwin and Yeomans and Mewhort et al in that it contends that location information is lost in the first buffer. That is, the first buffer consists of quickly decaying identity codes for the items in the stimulus, which are processed in parallel, and even more rapidly decaying location codes. The second buffer consists of a more durable storage of stimulus identity with some location information. The translation from the first buffer to the second is contended to be effortful and time consuming, rather than the automatic process proposed by the other two models.

This model explains Dixon's data by contending that, at short positive SOA's, little or no information has been transfered from the first buffer to the second before the probe appears for processing. Therefore, the comparison is made between the durable second buffer representation of the probe and the quickly decaying codes in the first buffer which includes the original representation of the probe. Since location information has decayed a great deal by this time, there is no way to tell whether the first stage representation of the probe is the probe or a stimulus item. Therefore, there is a high rate of false positives, and thus low accuracy in the absent conditions. If there is actually a dissociation of identity and location, as this model assumes, this is indeed an adequate explanation of the data it intends to explain. If, however, there is no such dissociation, then an alternative model must be found.

As you can see, the assumption that identity and location are stored separately with location information decaying more quickly is prevalent in contemporary accounts of iconic memory. Therefore, it seems reasonable to test this assumption in a set of experiments designed expressly for this purpose.

A Test of Independence of Identity and Location Information in Iconic Memory

The experiments described below were designed to investigate the coding of location and identity information in a new way, using a recognition memory procedure instead of a recall procedure. Recognition tests of memory are generally regarded as more sensitive (e.g., Baddeley, 1976), and thus perhaps less subject to retrieval biases. If we find identity and location to be independently coded, we will add support to the central assumption of the several new models of iconic memory mentioned above. If, however, we find that location and identity are not coded separately, these models will have to be discarded or modified to a greater or lesser extent.

Experiment 1

In Experiment 1 we used a recognition memory procedure to investigate performance in two conditions which differentially emphasized location and identity coding. In one condition (the *no arrow* condition), subjects were presented a circular array of 8 letters. This array was followed by a single probe letter presented in the center of the array; the subjects' task in this condition was to say whether the probe letter had appeared in the array. This condition thus required subjects to respond on the basis of identity information, with no regard for location information. The second condition was quite different, however. In this condition (the *arrow* condition), the probe consisted of a letter presented in the center of the array, along with a line which pointed to one of the array locations; the subjects' task in this condition was to say whether the probe letter had occupied the position pointed to by the line. Thus, this condition forced subjects to respond on the basis of both location and identity information. In trials in which the probe letter did not appear at the probed location, we examined what effect having the probe letter at another, unprobed location, had on performance. If identity and location information are stored separately, with location information decaying more rapidly, we would expect that the presence of the probe letter at an unprobed position would result in many incorrect "yes" responses as probe delay increased, because location information will have decayed and the probe's identity code will match the identity code of one of the elements in the array. An additional manipulation in both conditions was the presentation of a masking stimulus immediately after array offset on half the trials. If there is a difference in the coding of location and identity information, we thought it might be magnified under conditions of masking (cf., Chow, 1986; Irwin & Yeomans, 1986; Mewhort et al., 1981).

Method

Subjects. Thirteen adults associated with the university participated as subjects. All reported normal or corrected-to-normal vision. Each was paid $3 for each of four 1-hr sessions. All were naive as to the purposes of the experiment. Three subjects failed to perform above 55% accuracy (chance = 50%), so their data were excluded from analysis.

Apparatus and Materials. Stimuli were presented on a Hewlett-Packard 1340A point-plotting scope equipped with P31 phosphor. A Digital Equipment Corporation Micro-11/23+ computer controlled stimulus presentation via digital-to-analog converters. The stimulus display consisted of a circular array of 8 uppercase letters chosen randomly without replacement from the set of all consonants excluding y. Each letter in the display subtended 0.4 deg horizontally and 0.6 deg vertically, and the entire display subtended 4.2 deg. The probe on no-arrow trials was a single letter plotted in the center of the circular array; on arrow trials this letter was accompanied by a line approximately 1.1 deg in length that pointed to one of the locations in the circular array. The masking stimulus consisted of 8 individual dot matrices, one for each of the 8 array locations; each individual dot matrix subtended 0.4 deg horizontally and 0.6 deg vertically. Subjects indicated their responses by pressing keys on the keyboard of a Digital Equipment Corporation VT-240 terminal attached to the computer. The experimental chamber was illuminated in order to prevent subjects from detecting phosphor decay.

Procedure. Subjects began each trial by hitting the return key on the terminal keyboard. Five hundred ms later, the stimulus array was presented for 50 ms. On half the trials, the masking stimulus was then presented for 30 ms immediately after stimulus offset, while on the other half nothing was presented for 30 ms. Either 50, 100, 150, 200, 250, 300, 350, or 500 ms after array offset the probe was presented for 50 ms in what had been the center of the array. As described earlier, on half the trials (no arrow trials), the probe consisted of a single letter; the subjects' task on these trials was to indicate whether the probe appeared in the stimulus array. On the other trials (arrow trials), the probe consisted of a single letter and a line pointing to one of the array locations. On these trials, the subjects' task was to indicate whether the probe letter had appeared in the indicated position. False arrow trials were of two types: The probe letter was present in the stimulus display, but not in the probed position (*false presents*); or the probe letter was not presented in the stimulus array at any position (*false absents*). Subjects indicated their responses by pressing one key on the terminal keyboard for "true" and a different key for "false." Feedback was presented for 1 sec after this response.

Each subject completed 4 practice blocks and 20 experimental blocks of

128 trials each over four days. Each block contained 4 replications of the factorial combination of probe type (arrow vs. no arrow), mask (present vs. absent), and probe delay (50, 100, 150, 200, 250, 300, 350, or 500 ms); false arrow trials were equally divided between false absents and false presents. Probe type, mask presentation, and probe delay were sequenced randomly within each block of trials.

Results and Discussion

The analysis consisted of two major parts. The first part concerned overall accuracy in each condition. The second part concerned accuracy on the two types of false trial used on arrow trials. Figure 3 shows the results for arrow and no-arrow trials under both masked and nonmasked conditions as a function of probe delay. A 2 x 2 x 8 analysis of variance (collapsing over type of arrow false trial) with factors of probe type, mask, and probe delay revealed that accuracy was higher for arrow than for no-arrow trials [$F(1,9) = 64.5$, $p < .001$, $MSe = 148.6$], higher for nonmasked than for masked trials [$F(1,9) = 57.1$, $p < .001$, $MSe = 41.1$], and higher at short as compared to long probe delays [$F(7,63) = 5.51$, $p < .001$, $MSe = 36.5$]. In addition, there was a slightly larger masking effect (7.1% vs. 3.7%) for arrow trials than for no-arrow trials [$F(1,9) = 4.9$, $p < .06$, $MSe = 47.8$], and the difference between arrow and no-arrow trials, though significant at all probe delays, was greater at probe delays of 200 ms and under than at probe delays greater than 200 ms [$F(7,63) = 2.6$, $p < .02$, $MSe = 31.9$]. This pattern arose because accuracy for no-arrow trials was essentially constant across probe delay, whereas accuracy for arrow trials declined as probe delay increased. The results of this analysis reveal that our new recognition method of measuring very short-term visual storage yields results very

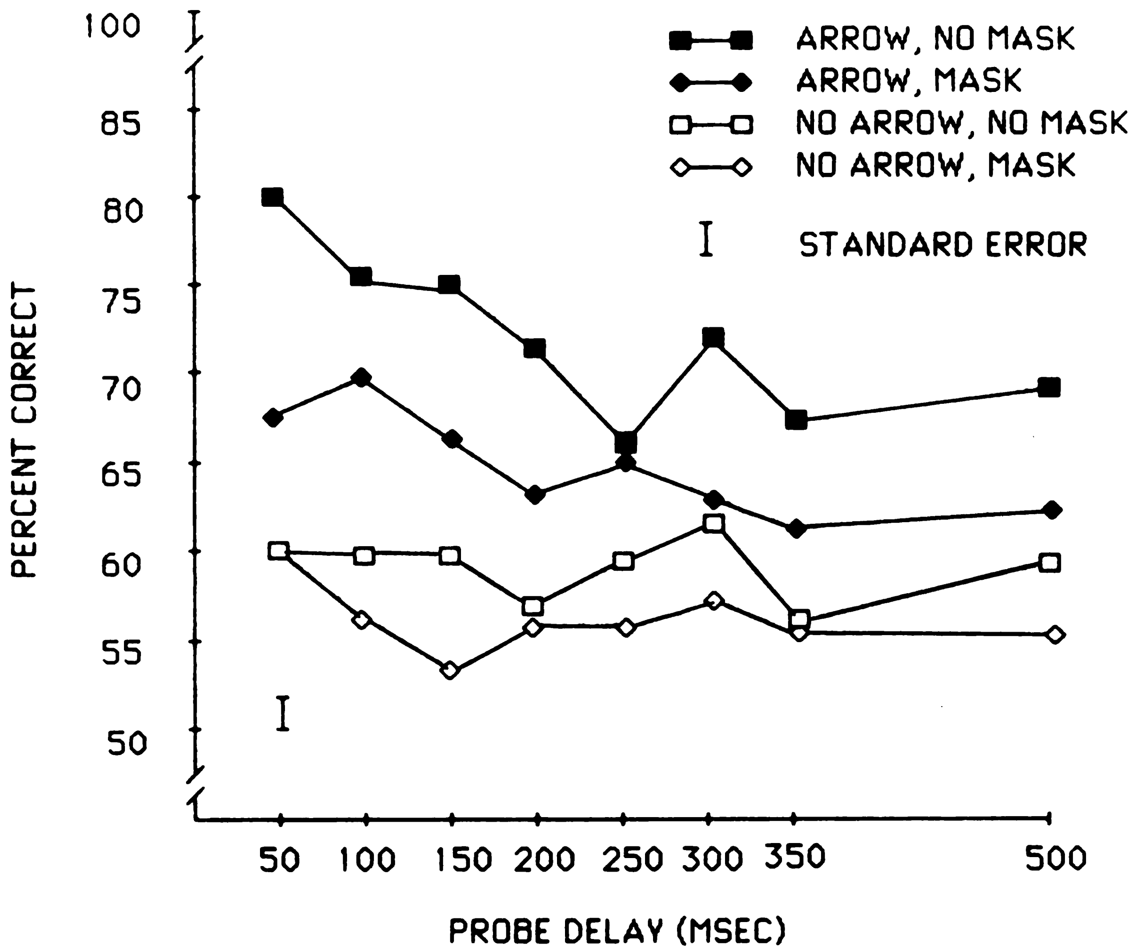

Figure 3. Experiment 1: Percent accuracy for arrow and no arrow trials

similar to those obtained in partial-report experiments: Accuracy declined as probe delay increased when both location and identity information were required for responding, and mask presentation interfered with performance. What is not known, however, is whether it is a loss of location information which is responsible for the drop in accuracy as probe delay increases, as previous theorists (e.g., Mewhort et al., 1981; Townsend, 1973) have argued. In order to evaluate this possibility, we conducted a second analysis which examined performance on false present and false absent trials in the arrow condition.

To review the logic of this second analysis, if the drop in accuracy with increasing probe delay is due to a more rapid decay of location information over identity information, then we would expect accuracy to be lower on false present trials (those in which the probe letter is in an unprobed location) than on false absent trials (those in which the probe letter is not in the array). This becomes obvious if one considers the time at which location information has decayed to zero but identity information is still available. At this point, on false present trials subjects would know that the probe letter was in the array but they would have no idea where it was, leading to some incorrect "yes" responses; on false absent trials, however, there would be no such confusion so accuracy would be high. In order to test this idea, we examined just the "false" data from the arrow trials of this experiment. A 2 x 2 x 8 analysis of variance with factors of false type (present vs. absent), mask (present vs. absent), and probe delay revealed that accuracy was higher for nonmasked than for masked arrays [$F(1,9) = 14.1$, $p < .005$, $MSe = 107.2$] and that accuracy declined as probe delay increased [$F(7,63) = 3.0$, $p < .009$, $MSe = 165.6$]. No effect involving type of false trial was found. The data for false present and false absent trials are shown in figure 4, collapsed over the masking variable because it did not interact with either probe delay or false type. What figure 4 reveals is that at longer probe delays accuracy was actually slightly higher on false present trials than on false absent trials, directly opposite to the prediction of the independence argument. In other words, at longer probe delays subjects actually performed better on "false" trials when the probe letter was in an unprobed position of the array than when it was absent from the array. This result suggests that location and identity are stored as a unit, rather than as separate codes with different decay rates.

Another result of Experiment 1 also suggests that location and identity information are nonindependent. Accuracy on arrow trials (which required both location and identity information) was superior to accuracy on no-arrow trials (which required only identity information) at all probe delays; if identity and location are stored separately, then performance on no-arrow trials should be superior to performance on arrow trials, because only one source of information (identity) would be needed for a correct response. This result not only shows that location and identity are stored together, but that they are stored in such a form that retrieval is aided by the addition of a location cue. The implications of this will be discussed after Experiment 2.

To summarize, under recognition-memory conditions evidence was found for the nonindependence of location and identity information, even though under recall conditions (i.e., partial report) location appears to decay before identity. It may be, as mentioned earlier, that recall conditions induce subjects to stress identification over localization at encoding or retrieval time, producing an inaccurate portrayal of the way in which information is stored in memory.

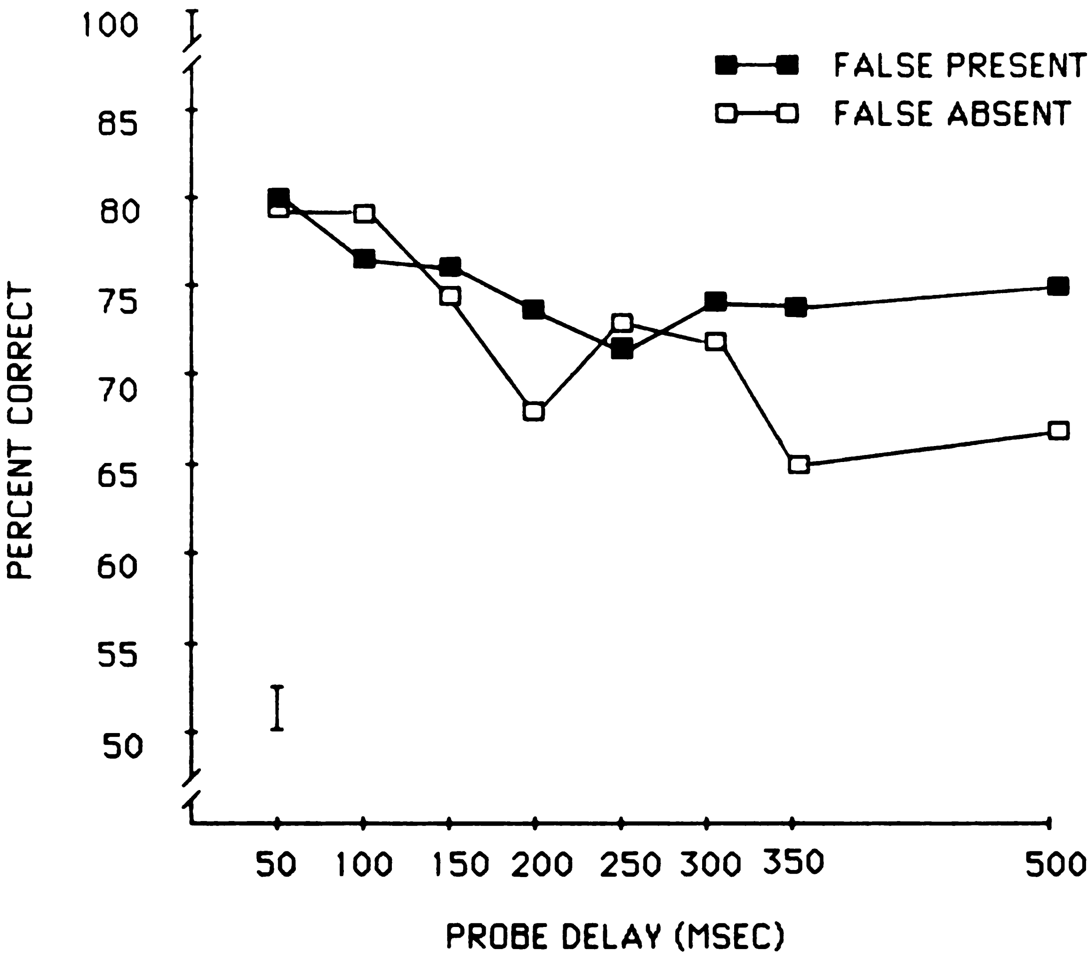

Figure 4. Experiment 1: Percent accuracy for false present and false absent trials.

However, although the results of Experiment 1 indicate that location and identity are stored together, the longest probe delay used in this experiment was 500 ms. Thus, it is possible that not enough time elapsed between stimulus offset and probe presentation to allow any possible dissociation between the two sources of information to occur. This seems unlikely, because partial report experiments have found location errors to outnumber intrusion errors at much shorter intervals; nonetheless, we thought it necessary to replicate the arrow condition of Experiment 1 with longer probe delays to see whether location and identity information become separated at delays longer than 500 ms. This was the purpose of Experiment 2.

Experiment 2

Method

Subjects. Ten adults from the University community participated as subjects. All reported normal or corrected-to-normal vision. All were naive as to the purposes of the experiment. Each subject was paid $3 for a single one-hour session.

Apparatus and Materials. The apparatus was the same as used in Experiment 1. Only arrow trials were used in this experiment, however, and masks were never presented.

Procedure. Each subject completed a one-hour session which consisted of one practice block and five experimental blocks. Each block consisted of 128 trials of the arrow, no mask condition from Experiment 1. As in Experiment 1, there were equal numbers of true and false trials, and, within false trials, an equal number of trials in which the probe letter was present at an unprobed position and trials in which the probe letter was absent from the array. Unlike Experiment 1, however, only four probe delays were used: 50, 350, 650, and 1000 ms. The longer probe delays were used to determine whether identity and location become dissociated at longer intervals.

Results and Discussion

Figure 5 shows the results for true, false absent, and false present trials as a function of probe delay. An analysis of variance of overall accuracy collapsed across true/false showed that accuracy declined as probe delay increased [$F(3,27) = 6.8$, $p < .002$, $MSe = 25.6$]. A second analysis of just the false trials with factors of false type (present vs. absent) and probe delay (50, 350, 650, 1000 ms) revealed a higher level of accuracy (65.9% vs. 62.4%) for false present trials than for false absent trials [$F(1,9) = 8.7$, $p < .02$, $MSe = 28.3$] and a decline in accuracy with increasing probe delay [$F(3,27) = 2.8$, $p < .06$, $MSe = 110.7$], but no interaction between false type and probe delay [$F < 1$]. In other words, we found that accuracy on false trials was significantly higher when the probe letter was present in the array at an unprobed position than when the probe letter was absent from the array. In Experiment 1 we had found a nonsignificant trend in this direction; with the greater power of this experiment, the difference achieved significance. This finding is incompatible with the independence hypothesis, because if location and identity information are stored separately, one would expect lower accuracy on false present trials because of confusion generated by the probe letter matching the identity code of one of the array elements. Thus, even at probe delays as long as 1 sec no evidence was found for a dissociation between location and identity information.

A question which arises from this experiment is why false present trials are superior to false absent trials. This finding may actually constitute additional support for the hypothesis that location and identity information

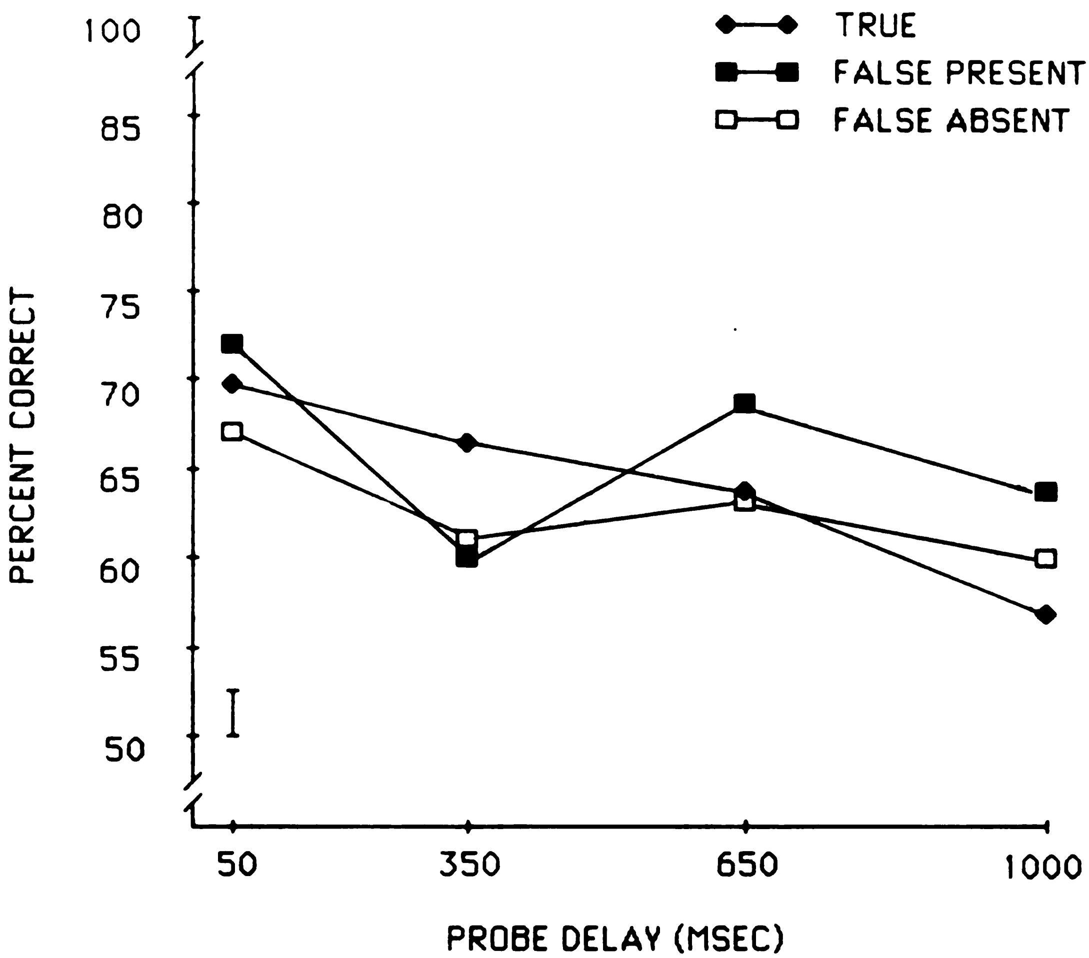

Figure 5. Experiment 2: Percent accuracy for true, false present, and false absent trials.

are stored together, based on the following argument. If location and identity are linked, then on false present trials the subject actually has two ways of reaching the correct response: the subject may note that the probe letter does not match the letter in the probed position, or the subject may note that the probe letter actually appears in an unprobed position and thus couldn't possibly also appear at the probed position. On false absent trials, however, the subject can make a correct response only by comparing the probe letter with the letter occupying the probed position. This state of affairs also holds for "true" trials, of course, and figure 5 shows that accuracy for false present trials was generally higher than accuracy for true trials.

In sum, the results of Experiment 2 replicate and extend the arrow condition results of Experiment 1, and further strengthen the argument that location and identity information are stored together, rather than separately. These results are problematical for the several models of iconic memory mentioned earlier which assume that location and identity are independent, with separate rates of decay. They also raise the question of the nature of the memory representation underlying performance in iconic memory experiments. That is, in what kind of memory representation are location and identity linked as a unit?

Two possibilities come to mind. The first, and perhaps most obvious, is that the memory representation is image-like in form. An image-like conception of iconic memory can easily explain both the nonindependence of location and identity information found in Experiments 1 and 2 (images, by nature, store form and location as a unit), and the superiority of arrow trials over no-arrow trials found in Experiment 1; if the storage were in the form of an image, then the arrow would aid in scanning the image by directing attention to the only pertinent position in the array, whereas in the no-arrow condition the whole image would have to be scanned.

But these two findings can also be explained by an abstract, non-image-like conception of iconic memory. Such a representation might consist of abstract identity codes with associated location coordinates; for example, subjects might code the contents of a circular array such as those used in the present experiments as "B-1, M-2, G-3" and so on, and compare the probe against this list. This conception of iconic memory could account for the superiority of arrow trials over no-arrow trials in either of two ways. First, if the representation is location-addressable, subjects could use the arrow to access the identity code linked to the probed location, then compare it with the probe letter's identity code; on no-arrow trials, however, the probe letter would have to be compared with all the array elements. Second, even if the representation is not location-addressable, fewer comparisons would need to be made on arrow trials than on no-arrow trials. No-arrow probes would require 8 comparisons (given our 8 item arrays) on negative trials, and 4.5 comparisons (on the average) on positive trials. But arrow probes contain two pieces of information, an identity code and a location code, and this reduces the number of comparisons that would have to be made on negative trials because a mismatch of either location or identity is sufficient to specify a negative response. Thus, on positive trials, 4.5 comparisons (on the average) would still be needed to detect a match between the probe and an array element, but on negative trials, only 4.5 comparisons (on the average) would be required on false absent trials and only 2.25 (on the average) would be required on false present trials for a mismatch to be found. Based on the assumption that fewer comparisons leads to superior performance, either of these nonvisual conceptions of iconic memory could account for the finding of higher accuracy on arrow as opposed to no-arrow trials.

Perhaps the most important point about these alternative conceptions of iconic memory is that they all hold that location and identity are stored as a unit, in contrast to the other models of iconic memory described earlier. Nonetheless, it would be satisfying and informative to discriminate between these alternatives. Unfortunately, the results of the first 2 experiments are insufficient for this purpose; so, we conducted a third experiment in which we varied the codability of the elements in the stimulus array in an attempt to test between the image and non-image conceptions of iconic memory.

Experiment 3

In order to discriminate between the image and non-image conceptions of iconic memory, in Experiment 3 we used stimuli that would presumably be easier to store in one form than another. Specifically, we used pseudoletters constructed by rearranging the lines of our letter stimuli. Since these pseudoletters are novel visual stimuli, they presumably lack abstract identity codes. Thus, if iconic memory is abstract in nature, recognition memory performance with these stimuli should be quite poor. If iconic memory is image-like in nature, however, recognition memory performance with these stimuli should be similar to performance with letter stimuli. Overall accuracy for the pseudoletter stimuli may be less than for letter stimuli, simply for reasons of familiarity, but in other respects performance for the two types of stimuli should be very similar.

Another, intermediate pattern of results might be obtained as well, however. Several models of iconic memory assume that persistence consists of two components, a raw, image-like, precategorical representation and an abstract, non-image-like, postcategorical representation (e.g., Irwin &

Yeomans, 1986; Mewhort et al., 1981). For brief exposures such as those used in the present experiments, these models assume that the image-like representation is present immediately after stimulus offset, but is then replaced by the postcategorical representation. Based on these models of iconic memory, we would expect letter and pseudoletter stimuli to exhibit similar performance at short probe delays, but then at some critical probe delay pseudoletter performance should drop dramatically as the transition from an image-like to an abstract representation is made.

Method

Subjects. Ten adults associated with the University participated as subjects. All reported normal or corrected-to-normal vision, and all were naive as to the hypotheses under study. Each subject was paid $3 for each of two one-hour sessions.

Apparatus and Materials. The equipment used was the same as in the previous experiments. Two types of stimuli were used, however. The first type was simply the set of 20 consonants used in the previous experiments. The second type was a set of 20 letter-like stimuli (pseudoletters) constructed by rearranging the lines composing the letter stimuli. These pseudoletters had the same dimensions as the letter stimuli and they were designed to not resemble any letter or any common symbol; these stimuli are shown in Figure 6. The stimulus array thus consisted of a circular array of 8 letters or 8 pseudoletters; the probe was always of the arrow variety, containing a letter or a pseudoletter and a line pointing to one of the array

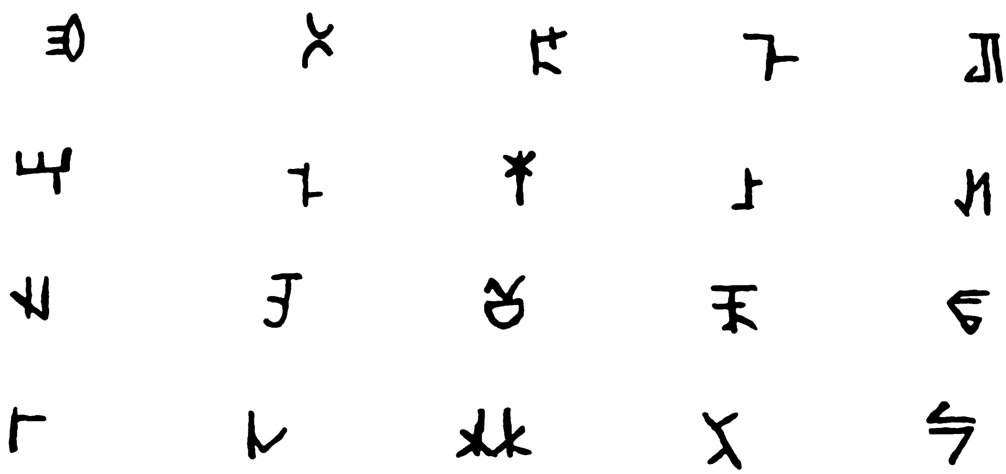

Figure 6. Pseudoletter stimuli used in Experiment 3.

positions.

Procedure. Each subject completed 12 blocks of 128 trials each over a 2-day period. In half the blocks letters were used as stimuli, and in the other half pseudoletters were used as stimuli. This assignment alternated from block to block; half the subjects started with a letter block and half with a pseudoletter block. The first block with each type of stimulus was discarded as practice.

Subjects began each trial by hitting the return key on the terminal keyboard. Five hundred ms later, the circular array of 8 letters or 8 pseudoletters was presented for 50 ms. Then, either 50, 100, 150, 200, 250, 300, 350, or 500 ms later, the probe was presented. The probe consisted of a letter (in letter blocks) or a pseudoletter (in pseudoletter blocks) and a line pointing to one of the array positions; the subjects' task was to indicate whether the probe letter (or pseudoletter) had appeared in the indicated position. "False" trials were of two types: The probe letter (or pseudoletter) was present in the stimulus display but not in the indicated position (false presents), or the probe letter (or pseudoletter) had not appeared in the display (false absents). Feedback was presented after each response. Each block of 128 trials consisted of 8 "true" trials and 8 "false" trials at each of the 8 probe delays; probe delay and trial type were sequenced randomly within each block of trials.

Results and Discussion

The analysis consisted of two parts. The first part concerned overall accuracy in each condition; Figure 7 shows the accuracy results for letter and pseudoletter stimuli as a function of probe delay. A 2 x 8 analysis of variance with factors of stimulus type (letter vs. pseudoletter) and probe delay (50, 100, 150, 200, 250, 300, 350, 500) revealed that accuracy

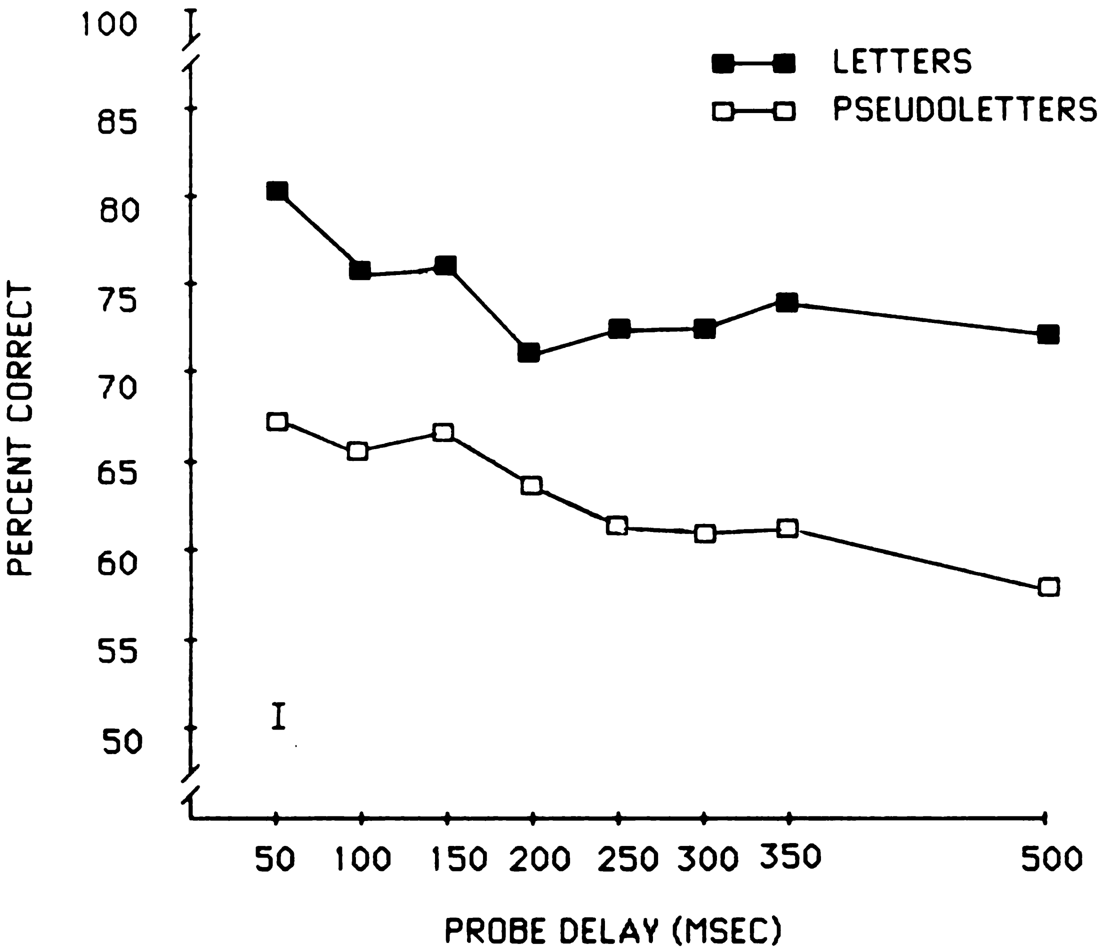

Figure 7. Experiment 3: Percent accuracy for letter and psuedoletter stimuli.

declined as probe delay increased [$F(7,63) = 5.8$, $p < .001$, MSe = 29.6] and that accuracy was higher (74.6% vs. 62.9%) on letter trials than on pseudoletter trials [$F(1,9) = 256.0$, $p < .001$, MSe = 21.2]. No interaction was found between these two variables [$F(7, 63) = 1.2$, $p > .3$, MSe = 22.4], however.

The second analysis concerned accuracy on the two types of false trials; Figure 8 shows the results for false presents and false absents as a function of probe delay for both letter and pseudoletter stimuli. A 2 x 2 x 8 analysis of variance with factors of false type, stimulus type, and probe delay revealed that accuracy was higher (79.2% vs. 59.2%) for letter trials than for pseudoletter trials [$F(1,9) = 39.1$, $p < .001$, MSe = 816.4]. Note that although accuracy on pseudoletter false trials was near 50%, this doesn't represent near-chance performance; performance would be near chance only when the total accuracy of true and false trials together is 50%. There was also a marginal main effect of false type, due to slightly higher accuracy (69.9% vs. 68.5%) on false present trials than on false absent trials [$F(1,9) = 2.9$, $p < .13$, MSe = 59.4]. No other main effects or interactions were significant. An additional analysis was conducted to determine whether the non-significant trend toward an advantage for false absent trials found in the pseudoletter condition might be significant in early blocks of trials when name codes are less likely to occur. To this end an analysis was conducted with block number as a factor. Though there was a main effect for block number, it did not interact with any other factor and so the entire analysis is not included.

The results of the second analysis again provide no evidence that location information decays before identity information. Accuracy for both letters and pseudoletters was slightly higher for false present trials than for false absent trials, directly counter to the predictions of the independence

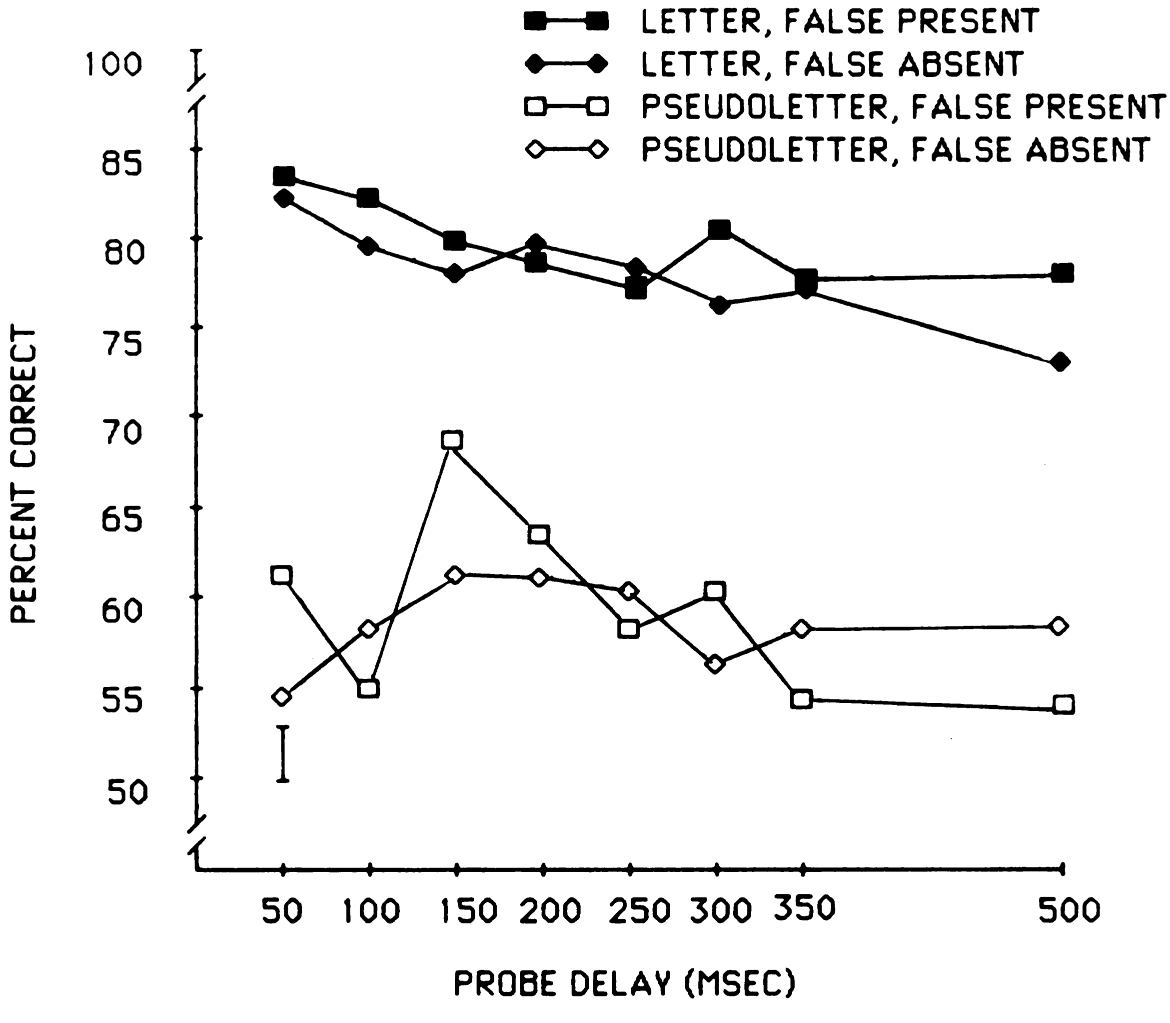

Figure 8. Experiment 3: Percent accuracy for false present and false present letter and pseudoletter stimuli.

argument. This result supports our earlier finding that location and identity information are stored as a unit, and further shows that this is true for pseudoletter stimuli as well as letter stimuli.

This result, along with the results of the first analysis, also allows us to tentatively discriminate between the image and non-image conceptions of iconic memory. The results of the first analysis show that accuracy for pseudoletters was significantly above chance at each probe delay, and furthermore showed the same decay over probe delay as did the letter stimuli; these results indicate that abstract identity codes (which pseudoletters presumably lack) do not form the basis of iconic memory. In other words, these findings are more consistent with an image-like conception of iconic memory, rather than an abstract conception. Nor was there any evidence for a dual-buffer conception of persistence, since the difference in accuracy between letters and pseudoletters did not change as probe delay increased.

In summary, the results of the third experiment also indicate that location and identity are nonindependent, and furthermore suggest that form and location information are stored in an image-like representation. Of course, this final conclusion is based on the assumption that it takes longer than two experimental sessions to develop identity codes for pseudoletter stimuli; furthermore, it is possible to conceive of an abstract representation which is based not on name or identity codes but on feature lists or some such stimulus description. Unfortunately, this possibility is not testable using the present paradigm. What we can say, however, is that if iconic memory is abstract in nature, it must not rely on name codes as its unit of storage, or it develops these codes very rapidly.

General Discussion

The purpose of the present research was to test the hypothesis that location and identity information about the contents of briefly presented visual displays is stored separately, with different rates of decay. Although previous research using recall measures of memory (e.g., partial report) has shown that location errors are much more common than intrusion errors, the results of our three experiments using a recognition test of memory indicate that location and identity are stored as a unit. There was no evidence that location information decays more quickly than identity information.

The partial report technique is an indirect method of assessing the storage characteristics of iconic memory, because some transformation of the information stored in memory may be necessary in order for a response to be produced. Thus, it is possible that the preponderance of location errors over intrusion errors found in partial report tasks is due to retrieval or response biases rather than to differences in the way in which location and identity information are stored in memory. Partial report experiments almost always use letters or numbers as stimuli; since subjects have had much more experience with the overlearned identity codes associated with these stimuli than with the location coordinates associated with any particular experimental display, it may not be too surprising that under conditions of uncertainty subjects prefer to report a character they know was present in the stimulus array (thereby making a location error) rather than reporting a character that may have been absent. Our recognition test of iconic memory eliminates this kind of response bias and yields a more direct measure of memory storage per se, revealing that in fact location and identity are stored as a unit.

These results have negative implications for the several models of iconic memory which have assumed that location and identity information decay at different rates (e.g. Irwin & Yeomans, 1986; Mewhort, et al, 1981; Dixon, 1986). Furthermore, the results of Experiment 3 showed that pseudoletter stimuli, which presumably lack abstract identity codes, are stored in a fashion similar to letter stimuli. This finding suggests that iconic memory is image-like in nature, rather than some abstract representation of location and identity information. This, too, is inconsistent with the models of iconic memory mentioned above.

The model of iconic memory proposed by Irwin and Yeomans (1986) was based on several partial report experiments which showed that presentation of a masking stimulus 150-300 ms after stimulus offset interfered with report, regardless of stimulus duration, although accuracy did increase as stimulus duration increased. These results were interpreted as evidence for a two-store model of iconic memory, the first a fast-decaying, duration-independent, maskable representation, and the second a durable, nonmaskable, abstract identity representation. The results of the present research suggest that this second memory store is in fact image-like in nature, rather than abstract. It is important to note that the only remaning evidence for a two-store model of iconic memory is the masking data of Irwin and Yeomans. It is possible that the recognition paradigm used in these experiments might find different results than those found in the masking experiments of Irwin and Yeomans and might allow us to dispense with a two stage model altogether.

Although the concept of a nonmaskable image seems counterintuitive, there is other experimental evidence for the existence of such a representation. For example, Posner, Boies, Eichelman, & Taylor (1969), using the Posner and Keele (1967) letter-matching procedure, found that a reaction time advantage for physical matches (AA) over name matches (Aa) is found even when a noise mask is presented between the first and second letters. Similarly, Phillips (1974) found that accurate same/different judgments of random dot patterns could be made even if a mask was presented between the two patterns being compared. These results provide strong support for the existence of nonmaskable, image-like representations in memory.

In conclusion, the results of the present research indicate that location and identity information about the contents of a briefly-presented visual display is stored in a unified, image-like form, rather than as separate abstract codes with different rates of decay.

LIST OF REFERENCES

Adelson, E. H., & Jonides, J. (1980). The psychophysics of iconic storage. Journal of Experimental Psychology: Human Perception and Performance, 6, 486-493.

Baddeley, A. D. (1976). The psychology of memory. New York: Basic Books.

Bowen, R. W., Pola, J., & Matin, L. (1974). Visual persistence: Effects of flash luminance, duration, and energy. Vision Research, 14, 295-303.

Coltheart, M. (1980). Iconic memory and visible persistence. Perception & Psychophysics, 27, 183-228.

Coltheart, M., Lea, C. D., & Thompson, K. (1974). In defence of iconic memory. Quarterly Journal of Experimental Psychology, 26, 633-641.

Chow, S. L. (1986). Iconic memory, location information, and partial report. Journal of Experimental Psychology: Human Perception and Performance, 12, 455-465.

Den Heyer, K. (1972). The processing of multidimensional information from iconic storage: Perceptual independence and comparative rates of decay. Acta Psychologica, 36, 431-442.

Dick, A. O. (1969). Relations between the sensory register and short-term storage in tachistoscopic recognition. Journal of Experimental Psychology, 82, 279-284.

Dick, A. O. (1974). Iconic memory and its relation to perceptual processes and other mechanisms. Perception & Psychophysics, 16, 575-596.

Di Lollo, V. (1978). On the spatio-temporal interactions of brief visual displays. In R. H. Day & G. V. Stanley (Eds.), Studies in perception (pp. 39-55). Perth: University of Western Australia Press.

Di Lollo, V. (1980). Temporal integration in visual memory. Journal of Experimental Psychology: General, 109, 75-97.

Dixon, P. (1986). Attention and interference in the perception of brief visual displays. Journal of Experimental Psychology: Human Perception and Performance, 12, 133-148.

Efron, R. (1970). Effect of stimulus duration on perceptual onset and offset latencies. Perception & Psychophysics, 8, 231-234.

Eriksen, C.W., & Collins, J.F. (1968). Initial traces versus the psychological moment in the temporal organization of form. Journal of Experimental Psychology, 77, 376-382.

Garner, W. R., & Morton, J. (1969). Perceptual independence: Definitions, models, and experimental paradigms. Psychological Bulletin, 72, 233-259.

Haber, R. N., & Standing, L. (1969). Direct measures of short-term visual storage. Quarterly Journal of Experimental Psychology, 21, 43-54.

Haber, R. N., & Standing, L. (1970). Direct estimates of the apparent duration of a flash. Canadian Journal of Psychology, 24, 216-229.

Irwin, D. E., & Brown, J. S. (in press). Tests of a model of informational persistence. Canadian Journal of Psychology.

Irwin, D. E., & Yeomans, J. M. (1986a). Sensory registration and informational persistence. Journal of Experimental Psychology: Human Perception and Performance, 12, 343-360.

Irwin, D.E. & Yeomans, J.M. (1986b). Persisting arguments about visual persistence : Reply to Long. Perception and Psychophysics, 39, 225-230.

Krumhansl, C. L. (1977). Naming and locating simultaneously and sequentially presented letters. Perception & Psychophysics, 22, 293-302.

Krumhansl, C. L., & Thomas, E. A. C. (1976). Extracting identity and location information from briefly presented letter arrays. Perception & Psychophysics, 20, 243-258.

Krumhansl, C. L., & Thomas, E. A. C. (1977). Effect of level of confusability on reporting letters from briefly presented visual displays. Perception & Psychophysics, 21, 269-279

Logan, G. D. (1975). On the independence of naming and locating masked targets in visual search. Canadian Journal of Psychology, 29, 51-58.

Long, G. M., & Beaton, R. J. (1980). The contribution of visual persistence to the perceived duration of brief targets. Perception and Psychophysics, 28, 422-430.

Long, G. M., & Beaton, R. J. (1982). The case for peripheral persistence: Effects of target and background luminance on a partial-report task. Journal of Experimental Psychology: Human Perception and Performance, 8, 383-391.

Mewhort, D. J. K., Campbell, A. J., Marchetti, F. M., & Campbell, J. I. D. (1981). Identification, localization, and "iconic" memory: An evaluation of the bar-probe task. Memory & Cognition, 9, 50-67.

Mewhort,D.J.K., Marchetti, F.M., Gurnsey, R., & Campbell, A.J. (1984). Information persistence: A dual-buffer model for initial visual processing. In H. Bouma & D.G. Bouwhuis (Eds.), Attention and Performance X (pp207-298). London: Erlbaum.

Neisser,U. (1967). Cognitive Psychology. New York: Appleton-Century-Crofts.

Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory. Perception & Psychophysics, 16, 283-290.

Posner, M. I., Boies, S. J., Eichelman, W. H., & Taylor, R. L. (1969). Retention of visual and name codes of single letters. Journal of Experimental Psychology Monograph, 79, (1, Pt. 2).

Posner, M. I., & Keele, S. W. (1967). Decay of visual information from a single letter. Science, 158, 137-139.

Sperling, G. (1960). The information available in brief visual presentations. Psychological Monographs, 74(11, Whole No. 498).

Sperling,G. (1967). Succesive approximations to a model for short-term memory. Acta Psychologica, 27, 285-292.

Townsend, V. M. (1973). Loss of spatial and identity information following a tachistoscopic exposure. Journal of Experimental Psychology, 98, 113-118.

Yeomans, J. M., & Irwin, D. E. (1985). Stimulus duration and partial report performance. Perception & Psychophysics, 37, 163-169.