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# The persistences of vision

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Human observers continue to experience a visual stimulus for some time after the offset of that stimulus.

The neural activity evoked by a visual stimulus continues for some time after its offset.

The information extracted from a visual stimulus continues to be registered in a visual form of memory ('iconic memory') for some time after its offset.

We may thus distinguish three distinct senses in which a visual stimulus may be said to persist after its physical offset: there is phenomenological persistence, neural persistence and informational persistence. Various assumptions have been made about the relation between these three forms of visual persistence. The most frequent assumption is that they correspond simply to three different methods for studying a single entity. Detailed consideration of what is known about the properties of these three forms of persistence suggests, however, that this assumption is not correct. It can reasonably be proposed that visible persistence is the phenomenological correlate of neural persistence occurring at various stages of the visual system: photoreceptors, ganglion cells and the stereopsis system. Iconic memory, on the other hand, does not correspond to visible persistence, nor to neural persistence in any stage of the visual system. Recent work, in fact, suggests that iconic memory is a property of some relatively late stage in the visual information-processing system, rather than being a peripheral sensory buffer store. This suggestion raises some fundamental theoretical issues concerning the psychology of visual perception, issues with which cognitive psychology has yet to come to grips.

## THREE PERSISTENCES OF VISION

Visual scientists have for a century or more used the term *persistence of vision* to refer to a variety of visual phenomena having in common that they suggest that visual sensation is prolonged for some time after the physical offset of the visual stimulus. In this paper I wish first of all to show that there are three qualitatively different types of visual phenomenon that have been described as persistences of vision. This ambiguity in the usage of the term persistence of vision has not always been recognized.

When this ambiguity *has* been recognized, the assumption has been made that the ambiguity is not important because the three types of visual effect are merely three sides of the same coin: three different ways of looking at the same entity. I shall suggest that this is not so, and that if confusion is to be avoided one must distinguish between these three senses of the term 'visual persistence', and acknowledge that they may be mediated by different mechanisms.

I shall begin by explaining what I mean by the claim that there are three kinds of visual persistence. Two were known to Newton in the seventeenth century, as the quotation from the *Opticks* reveals:

> And when a Coal of Fire moved nimbly in the circumference of a circle makes the whole circumference appear like a Circle of Fire; is it not because the Motions excited in the bottom of the Eye by the Rays of Light are of a lasting nature, and continue till the Coal of Fire in going round returns to its former place?

Here Newton proposed two things. The first is that the sensation produced by a visual stimulus continues to be experienced for some time after the physical offset of that stimulus. This observation belongs to the realm of phenomenology. Observations of this kind are often adduced in discussions of visual persistence. To refer to these effects I will use the term *visible* persistence.

Secondly, Newton hypothesized that the retinal activity produced by a visual stimulus continues to occur for some time after the physical offset of the stimulus. This is a hypothesis about neurophysiology, and the effect Newton speculated about will here be termed *neural* persistence.

Newton argued that visible persistence was explained by neural persistence in the retina. Clearly, however, this is only a hypothesis, and the relation between 'visible persistence' and 'neural persistence' must be elucidated by experiment. Furthermore, even if visible persistence is caused by neural persistence in the visual system, this persistence need not be entirely retinal; it need not be retinal at all.

The third form of persistence of vision was discovered by Sperling (1960). This discovery relied upon a methodological innovation, which I shall describe briefly. Suppose a visual display consisting of a 3 × 4 matrix of letters is presented to an observer for a brief period, say 50 ms. If the observer is asked to report as many of these letters as he can, he will average about 4.5 correct. This value is reasonably invariant across observers, laboratories, and indeed centuries, since experiments of this kind were carried out in the nineteenth century, with comparable results. Why is it that only about one-third of the letters in a brief 12-letter display can be reported? The answer to this question still eludes us; but certain obvious answers can be ruled out. Firstly, it might be that the visual recognition of items in a multi-item display is a serial process, and a display time of 50 ms permits only four of five individual acts of recognition. This can be ruled out, because if one shortens the display duration to 15 ms, or increases it to 500 ms, the number of items reported scarcely changes at all.

A second idea might be that the visual recognition of items is a parallel process, but one with limited capacity: it can deal with only four or five items at once, and after this some form of refractoriness intervenes. Thus only four or five of the items are stored in memory; the remaining seven or eight simply go unregistered.

Sperling's methodological innovation, *the partial-report technique*, provided evidence that ruled out this idea. When this technique is used, the subject is asked to report, not the entire display, but only some subset of the items. For example, on a particular trial he might be asked to report the items in the top row, or the red items, or the items containing a curved contour, or the highest-contrast items. Take the first of these as an example: one actually does the experiment by training an observer to associate a tone of high frequency with the top row, a medium frequency tone with the middle row and a low frequency tone with the low row.

Suppose, now, that the cue tone is presented to the subject immediately *after* the display has been switched off, and that the selection of high, medium and low tones is completely random. Under these conditions, the observer will be unable to predict during the physical presence of the display which of its three rows he will be asked to report. It will therefore be impossible for him to favour the items he is to report over other items in his visual processing during the physical duration of the display.

Now, if only four or five items from such a display can be registered in memory, and if these must be a random selection with respect to the row which will be cued, then it follows that the observer should be able to report $4.5/3 = 1.5$ items from the row which is cued. This was not so with Sperling's observers: they averaged three out of a maximum possible of four. This must mean that, at the time at which the observer learns from the cue which row he is to report, he must have available in memory at least three items from each of the three display rows, that is, at least nine items are registered in memory. This is so in spite of the fact that when observers attempt to report all of the items from the display, they average only 4.5 items. The difference between the estimates of items in memory obtained with the partial report and the full report method is known as the *partial-report superiority*. When Sperling studied the effect of varying the delay between display offset and cue onset, he found that the size of the partial-report superiority declined as the cue delay increased; at delays of several hundred milliseconds or a few seconds (depending upon experimental conditions) no superiority is observed.

These results suggest the following interpretation. Immediately after the offset of the display, most of its items are held in a form of memory which is of high capacity but which is subject to rapid decay. Any item that is to be reported must be transferred to a second form of memory which is not subject to rapid decay, and hence which permits leisurely report. Only about four or five items can be transferred in this way, but the observer is capable of choosing which of the items in the transient high-capacity memory are to be transferred to the more durable memory. For example, he can choose to transfer the top row of items, or the red items, or the items containing a curved contour, or the high-contrast items.

The transient high-capacity memory responsible for the partial report superiority was subsequently named *iconic memory* by Neisser (1967) and his term will be adopted here. This memory is our third form of persistence of vision. It is not phenomenologically defined, as is visible persistence; it is not a neurophysiological entity, as is neural persistence; its essential characteristic is that it is *informational*: it preserves in rapidly decaying form the information that was present in a visual display.

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

Consider now what relations may exist between these three visual phenomena. Newton believed, as we have seen, that visible persistence is the phenomenal manifestation of neural (specifically retinal) persistence. It is widely assumed that visible persistence is the phenomenal manifestation of iconic memory – that is, that iconic memory is visible. For example: 'the "short-term visual memory" of Sperling (1960) is a detailed texture memory but fades out in 0.1 sec like the afterglow of a cathode ray tube, and is merely an afterimage' (Julesz 1971, p. 103); and '(an) indicator of the visual persistence of a flash . . . yields data of the same high order of reliability and magnitude found by the far more laborious and indirect procedures of Sperling (1960)' (Haber & Standing 1970). Finally, iconic memory has been identified with neural persistence: 'the information about the icon is stored primarily inside the rod photoreceptors' (Sakitt 1975). A conflation of the views of Newton, Julesz, Haber and Sakitt results in the claim that visible persistence, neural persistence and iconic memory, are different manifestations of a single entity – the persistence of vision.

Despite the widespread nature of this claim, it has never been investigated or defended, except by Sakitt, whose work is discussed later. In particular, the identification of visible persistence with iconic memory is an assumption that has not been questioned, let alone defended.

One way of attempting to discover what the relations are between visible persistence, neural persistence and iconic memory is to determine what properties characterize each of these entities and to consider whether the three sets of properties coincide, as they must if visible persistence is neural persistence and neural persistence is iconic memory. I approach this by first surveying what is known about visible persistence.

## VISIBLE PERSISTENCE

### *Methods for the study of visible persistence*

Visible persistence has received much attention in the past 15 years, though its investigators have proceeded with a curious independence and a fine disregard for each other's findings. The basic phenomenon is that a visual stimulus goes on being visible for some time after its physical offset; and seven different experimental methods have been used in recent years to investigate this phenomenon.

(1) *Judgement of synchrony*. The physical offset of a visual test stimulus is followed after some delay by a brief probe stimulus. The observer adjusts this delay until the onset of the probe stimulus coincides exactly in time with the apparent disappearance of the visual test stimulus. The delay between test stimulus offset and probe stimulus onset is taken as a measure of the duration of visible persistence. This method has been used by Sperling (1967), Efron (1970*a*, *b*, *c*), Haber & Standing (1970) and Bowen *et al.* (1974).

(2) *Onset-offset reaction times*. In one block of trials, the observer responds as rapidly as he can to the onset of a visual stimulus. In another block, he responds as rapidly as he can to the offset of the stimulus. On the assumption that offset responses are made to the termination of the visible persistence of the stimulus, substraction of onset reaction time from offset reaction time provides a measure of the duration of visible persistence. This method has been used by Rains (1961), Pease & Sticht (1965), Bartlett *et al.* (1968) and Briggs & Kinsbourne (1972).

(3) *Stroboscopic illumination of a moving stimulus*. If a moving object is stroboscopically illuminated, and if velocity and flash rate are suitably chosen, the $n$th illumination of the object will occur while the visible persistence generated by the $(n-1)$th illumination is still present. Thus two objects will be seen. Increases in velocity or flash rate will cause three, four or more objects to be seen. From the maximum interflash time at which two objects are seen one can calculate the maximum duration of visible persistence. This method has been used by Allport (1966, 1970), Mollon (1969), Efron & Lee (1971) and Dixon & Hammond (1972).

(4) *Viewing through a moving slit*. When you walk beside a paling fence and look at a cricket match through the interstices of the fence, an appropriate speed of walking will allow you to see the scene as a whole, even though at any one instance only half of it, divided up into a series of vertical slices, is available to your retina. A simplification is to look at a figure hidden behind an opaque card on which a vertical slit is cut. As the slit is moved to and fro across the figure, the whole figure can be seen, provided the eyes are stationary with respect to the figure. This occurs because visible persistences of adjacent figure segments are generated on adjacent retinal areas. The slowest slit traverse time at which the whole figure remains continuously visible is a measure of the duration of visible persistence. This method has been used by Anstis & Atkinson (1967), Haber & Nathanson (1968), Haber & Standing (1969) and Stanley & Molloy (1975).

(5) *Phenomenal continuity*. When a visual stimulus is repeatedly switched on and off, it appears to be present continuously if the off-time is short enough, since the visible persistence of the

stimulus bridges this temporal gap. The maximum off-time at which the stimulus is phenomenally continuously present is a measure of the duration of visual persistence. This method has been used by Haber & Standing (1969), Meyer *et al.* (1975) and Meyer (1977).

(6) *Temporal integration of form parts.* This is Newton's coal-whirling technique. If a visual form is broken up into parts, and the different parts displayed at different times, the whole form will be seen, provided that the part displayed first is still visibly persisting at the time of presentation of the part displayed last. The maximum temporal interval between first and last parts at which the form is seen as a whole is a measure of the duration of visible persistence. This method has been used not only by Newton but also by Eriksen & Collins (1967, 1968), Pollack (1973), Hogben & di Lollo (1974), di Lollo (1977), di Lollo & Wilson (1978) and di Lollo (1980).

(7) *Stereoscopic persistence.* This method has been described in an important but neglected paper by Engel (1970). It has been known for many years that, if the two members of a stereoscopic stimulus-pair are briefly displayed to their respective eyes at different times, stereopsis can be experienced if the interstimulus interval is brief enough. This indicates that information from the leading stimulus must be available to the stereopsis mechanisms for some time after the offset of that stimulus. Engel's contribution was to investigate the persistence of the stereoscopic sensation itself. Given that two asynchronous stimuli, one to each eye, have generated a stereoscopic sensation, how long can one wait before re-presenting the two stimuli, without causing a discontinuity in the experience of stereopsis? Visible persistence of stereoscopic depth measured in this way can last as long as 300 ms after the offset of the lagging monocular stimulus.

### *Properties of visible persistence*

Studies with the use of these seven methods show that a visual stimulus continues to be visible for some hundreds of milliseconds after its physical offset. More importantly, these studies provide information about the relation between the duration of such visible persistence and two parameters of the stimulus: its duration and its intensity. In both cases, the relation is counter-intuitive. The greater the duration of the stimulus, the *shorter* is the time for which it continues to be visible after its offset (Efron 1970*a*, *c*; Haber & Standing 1970; Bowen *et al.* 1974; Briggs & Kinsbourne 1972; di Lollo 1977). The greater the luminance or contrast of the stimulus, the *shorter* is the time for which it continues to be visible after its offset (Bowen *et al.* 1974; Pease & Sticht 1965; Bartlett *et al.* 1968; Allport 1970; Efron & Lee 1971; Dixon & Hammond 1972; Haber & Standing 1969; Pollack 1973). I shall refer to these two results as the *inverse duration effect* and *the inverse intensity effect*. They provide a signature for visible persistence. Any phenomenon that is said to be reducible to visible persistence must itself display both of these effects; if it does not, then it cannot be identified with visible persistence. In addition, any hypothesis that seeks to explain visible persistence must be able to explain why there are inverse effects of duration and intensity.

Having described the methods used to study visible persistence, and the two properties of visible persistence revealed by experiments with the use of these methods, I turn now to the second persistence: neural persistence. My comments will be brief, since my acquaintance with visual neurophysiology is a superficial one. Nevertheless, I attempt to consider whether neural persistence occurs, and, if it does, at what locus or loci in the visual system it occurs. A discussion of this kind provides a basis for evaluating Newton's hypothesis that visible persistence is due to the lasting nature of the Motions excited in the bottom of the Eye by Light.

## NEURAL PERSISTENCE

The first locus that I shall consider is the late receptor potential (r.p.) of rods and cones. Recordings in the macaque monkey by Whitten & Brown (1973*a*, *b*, *c*) as well as in other species (rat, cat, mudpuppy) by Steinberg (1969), Penn & Hagins (1972) and Fain & Dowling (1973) have shown that both the rods and the cones continue to transmit signals for some time after stimulus offset. The cone signal, however, decays away rapidly, whereas the rod signal has a relatively long constant of decay (see, for example, Whitten & Brown 1973*a*, figs. 7, 9 and 14*a*). Therefore neural persistence exists at the photoreceptor level, especially in the rods. Consequently, one might make Newton's hypothesis more specific by identifying 'Motions excited in the bottom of the Eye' with 'receptor potentials', and proposing that visible persistence is due to the prolongation of the receptor potential.

Any hypothesis about the neural basis of visible persistence must be capable of explaining the inverse intensity and duration effects. This appears to present problems for a hypothesis based on the receptor potential, since Whitten & Brown (1973*a*) found that as stimulus intensity increased, both the rod r.p. and the cone r.p. increased in duration: in other words, there was a *direct* relation, not an inverse one, between stimulus intensity and duration of neural persistence. However, it may be possible to deal with this problem. It has been suggested by Whitten & Brown (1973*b*), Makous & Boothe (1974) and Stabell & Stabell (1976) that cones inhibit rods. In mesopic conditions, rod r.ps last longer than cone r.ps. As one increases intensity within the mesopic range, cones will respond more and more strongly, and hence exert greater and greater inhibition on rods. The net effect of this could be that the rod r.p. becomes shorter and shorter as intensity increases in the mesopic range, if the inhibitory effect of cones outweighs the direct effect of increasing intensity on the duration of the rod r.p. and since in the mesopic range the rod r.p. lasts longer than the cone r.p., the maximum duration of the r.p. could show an inverse intensity effect.

This argument cannot apply to scotopic or photopic vision; it therefore makes the strong prediction that the inverse intensity effect will only be obtained with intensities in the mesopic range, a prediction that would be simple to investigate. It seems probable that the studies of visible persistence demonstrating the inverse intensity effect have used intensities generally within the mesopic range; if there are any that have not, they would provide data relevant to the r.p. hypothesis.

Thus something (albeit speculative) can be said about the way in which the r.p. hypothesis can explain the inverse intensity effect. But what of the inverse duration effect? One might argue that the cone inhibitory effect accumulates while the stimulus is present. This could be investigated in experiments like those of Whitten & Brown if stimulus duration were varied systematically, something that they did not try. An alternative possibility is that, if the intensity effect operates at the r.p. stage, perhaps the duration effect operates the next stage – the ganglion cell?

When one records from retinal ganglion cells, at least two types of cell can be distinguished: transient cells and sustained cells. Sustained cells respond during the presence of the stimulus; after stimulus offset, their activity begins to diminish, and decays away relatively more slowly to the pre-stimulus level. This form of neural persistence might produce visible persistence.

It has been proposed by, for example, Breitmeyer & Ganz (1975) that transient cells inhibit sustained cells. If so, transient cells could act to curtail visible persistence. This might explain why visible persistence duration is shorter for low-frequency grating stimuli than for high-frequency grating stimuli (Meyer & Maguire 1977): transient cells are known to be selectively sensitive to low spatial frequencies.

Evoked-potential results reported by Servière *et al.* (1977*a*, *b*) might be taken as evidence that, when stimulus duration is varied, the latency of the transient off-response decreases linearly as stimulus duration increases, up to a stimulus duration of about 60 ms. At longer durations, off-response latency was independent of stimulus duration. If this off-response curtails visible persistence, then the relation between visible persistence duration and stimulus duration will be an inverse one up to some critical value, after which visible persistence duration will be independent of stimulus duration; this is the result obtained by Efron (1970*a*, *c*).

Thus the hypothesis that neural persistence of the sustained class of retinal ganglion cells is one basis for visible persistence may provide an explanation of the inverse duration effect. The hypothesis that persistence of the receptor potential is also aneural basis for visible persistence may provide an explanation of the inverse intensity effect. Even two neural loci are not enough, however, because the stereoscopic visible persistence studied by Engel (1970) must have a cortical locus.

These suggestions, the neurophysiological speculations of a cognitive psychologist, can be evaluated directly, simply by detailed comparisons between appropriate psychophysical data (obtained in experiments on visible persistence) and neurophysiological data (obtained in experiments studying neural persistence), and it is to be hoped that such data will become available. In the meantime, one can take the view that Newton may have been correct in proposing that visible persistence is due to neural persistence, although he would have to admit now that the neural persistence is not only in the 'bottom of the Eye' (receptors and ganglion cells) but also in the cortex (stereopsis system).

## Iconic memory

Having made some suggestions as to the relation beween visible persistence and neural persistence, we are left with two questions. The first is, what is the relation between iconic memory and visible persistence? The second is, what is the relation between iconic memory and neural persistence?

### *Iconic memory and visible persistence*

There is a fairly direct way of assessing the assumption (Julesz & Chiarucci 1973; Haber & Standing 1970) that iconic memory *is* visible persistence. If this assumption is correct, the duration of iconic memory will be greater for short or weak stimuli than for long or intense stimuli.

It has been demonstrated by Keele & Chase (1967), Eriksen & Rohrbaugh (1970), Scharf & Lefton (1970) and Adelson & Jonides (1978) that the duration of iconic memory does *not* diminish when stimulus intensity is increased. It has been demonstrated by Sperling (1960) and di Lollo (1978) that the duration of iconic memory does *not* diminish when stimulus duration is increased. Thus the inverse intensity and duration effects characteristic of visible persistence are not properties of iconic memory. In my view this represents a conclusive demonstration that iconic memory and visible persistence are completely different phenomena.

Further work relevant to this question which has been done is the investigation of iconic memory with direction of movement as the stimulus feature used in partial report. Russell

(1977), Treisman *et al.* (1975) and Demkiw & Michaels (1976) showed that when a display of moving stimuli was presented and followed by a cue requesting report of the direction of movement of the cued stimuli, typical iconic memory results were obtained. There was a partial report superiority which diminished as cue delay increased. Russell (1977) notes that his subjects did not report seeing a persisting impression of movement; yet their iconic memories included information about movement. A more rigorous argument could be developed if one carried out an experiment in which, by using one of the methods described earlier, the duration of visible persistence of movement was actually measured.

The third and final point to be made here concerns comparisons between the durations of visible persistence and of iconic memory. It is sometimes argued that these durations have been found to be roughly equal in magnitude, and this is offered as evidence that the two phenomena are really one. Such claims overlook an important factor in partial-report experiments: cue-decoding time. The subject must decode the partial-report cue to determine which subset of the items in iconic memory are requested for report. The decoding process cannot be instantaneous; it must take time. In fact, the time required to decode a partial report cue was measured by Averbach & Coriell (1961), and in their experiment this time was about 270 ms. This means that a cue presented simultaneously with display offset is not applied to the contents of iconic memory until 270 ms later, and during this time iconic memory will have decayed considerably. Hence estimates of the lifetime of iconic memory as derived from partial report experiments will be underestimates; they must be corrected by adding cue-decoding time, which can be as much as 270 ms. When this is done, then there is no longer much coincidence between the duration of iconic memory (as measured by partial report experiments) and the duration of visible persistence (as measured by any of the seven methods described earlier). Visible persistence durations are much shorter than iconic memory durations. This is clearest in data provided by Averbach & Sperling (1961), indicating an iconic memory lasting for some seconds; in all studies of visible persistence, its duration is considerably less than a second.

The relation of iconic memory to visible persistence needs further investigation, but, in view of the three points made here, it seems most unlikely that the claim of identity between iconic memory and visible persistence will be salvaged by further work.

### *Iconic memory and neural persistence*

Considerations of the relation between iconic memory and neural persistence have been brought into sharp focus by the work of Sakitt (1975, 1976*a*, *b*). Her view is that iconic memory and visible persistence are the same thing and that their neural basis is persistence of activity in rods and cones, the important factor being the neural persistence of rods, since cone persistence is much briefer than rod persistence. Here I shall consider her view that iconic memory depends upon photoreceptor persistence, especially rod persistence. It seems to me that there are a number of difficulties for this view.

The first point is that iconic memory includes information about direction of rotary or linear movement (Russell 1977; Treisman *et al.* 1975; Demkiw & Michaels 1976). How could the persisting activity of photoreceptors encode this kind of dynamic information?

Secondly, it seems unlikely that a brief visual stimulus could evoke in the rod system a burst of activity that persists for a second or more. None of the recordings of photoreceptor persistence in non-human species suggest that its duration can approach the duration of iconic memory as measured in partial report experiments.

Thirdly, experiments by Eriksen & Hoffman (1973) and Eriksen & Eriksen (1974) are difficult to interpret if one argues that the iconic memory for a visual display consists of a complex pattern of persistences in photoreceptors, and selection from iconic memory consists of selection of a part of this pattern for further analysis, the remainder of the sensory data receiving no further analysis. Eriksen and his colleagues used a row of three letters as a visual display. The subject's task was to classify the central letter; for example, to move a lever one way if it was an H or an M, and a different way if it was an A or U. The latency of this movement was influenced by the nature of the flanking non-target letters; latency was reduced if they belonged to the same category as the target letter, and increased if they belonged to the opposite category. Therefore on some occasions at least the non-target letters must have been categorized too. This shows that, even when there is no uncertainty at all as to which information in iconic memory is to be selected for further analysis and which is irrelevant, nevertheless the irrelevant information is also given further analysis to a profound level. The most natural interpretation of this is that all of the information in iconic memory has been given full analysis, and that iconic memory is not an early sensory stage in the information-processing sequence, but a late stage that *follows*, not precedes, stimulus identification. This is discussed further below.

Decisive work relevant to the assertion that iconic memory is photoreceptor (primarily rod) persistence remains to be carried out, however. There are at least two clear avenues to be pursued here. The first concerns iconic memory for colour. If cone persistence is very brief, then colour information should be available only very briefly in iconic memory. Therefore, if one can show that colour information persists in iconic memory for a relatively long time, this would be evidence against a photoreceptor locus for iconic memory. Several studies of this issue have recently been published (Banks & Barber 1977; Adelson 1978), but it is not yet established whether colour information does persist for relatively long durations in iconic memory.

A second important topic here is stereoscopic iconic memory. The general idea is that, if an iconic memory is generated by stereoscopic stimulation, it must be a cortical and hence not a retinal iconic memory. It would not be sufficient, however, to show that partial-report superiority occurs when a display is presented as a stereo pair. Persistence of the individual monocular stimuli at the photoreceptor level would be sufficient to account for a partial-report superiority in this stereoscopic situation. What is required is to adopt the methods of Engel (1970): these methods allow independent measurement of monocular persistence and stereoscopic persistence. If such an experiment showed that the duration of a stereoscopically generated iconic memory is too long to be accounted for in terms of persistence in monocular channels feeding the stereopsis system, then definitive evidence would have been obtained for the existence of an iconic memory whose neural locus is cortical, and hence evidence obtained against the view that iconic memory is photoreceptor persistence.

## *The nature of iconic memory*

In contemporary models of the psychology of perception, iconic memory is regarded as a peripheral buffer store which holds unprocessed visual information, allowing the processing mechanisms sufficient time to perform operations upon visual input in conditions where the display duration itself is too short to allow the completion of these operations. The partial report superiority is interpreted as an indication that the perceiver can perform these operations selectively, on certain items in iconic memory rather than on others.

It has been pointed out by van der Heijden (1978) that this view of the nature of iconic memory is at variance with another body of literature on the psychology of perception, namely, work showing that visual identification is non-selective and automatic. For example, the work of Eriksen described above indicates circumstances in which a subject cannot direct his processing operations to a certain item and away from other items, even when to do so would improve his performance. Van der Heijden (1978) showed that a subject's rapid naming of a colour patch presented to one side of a fixation point was affected by the nature of a printed word presented to the other side of the fixation point, even though the subject was not required to process the word in any way. These two examples suggest that subjects cannot use a spatial criterion to select certain unprocessed visual inputs for further processing and to prevent further processing of unwanted visual inputs. Instead, it appears that given adequate visual registration *all* inputs are processed, and selection follows this processing.

An attempt at demonstrating this directly is reported by Allport (1978). His tachistoscopic display consisted of four words. One was always the name of an animal. Subjects were asked to report as many words from a display as they could, but to give special priority to animal names. Suppose that the stage at which the information extracted from a visual display decays rapidly is before the stage at which items are identified. If this is so, requiring subjects to favour items belonging to a particular semantic category will be ineffective: the favouring of items operates at the rapidly decaying stage, whereas the semantic category of an item is not known until a subsequent stage. On this reasoning, which relies on the usual view of iconic memory as an early sensory buffer store, the subjects in Allport's experiment should be no better at reporting animal names than any other words from the display. However, report of animal names *was* superior. This suggests that there is significant rapid decay of information at some stage *after* the meanings of briefly displayed words have been established. If this rapid decay, responsible for partial report superiority, is the signature of iconic memory, then iconic memory is not a peripheral buffer store, but a much later stage in the system.

In my view, this conceptualization of the nature of iconic memory will gain ground rapidly in the future; experiments like those of Eriksen, van der Heijden and Allport will provide a body of evidence indicating that iconic memory is not an entirely pre-categorical or pre-identificatory system. At the same time, it must be admitted that this approach to the nature of iconic memory raises extremely difficult theoretical problems, which will be very briefly sketched here.

The meanings of words are represented in some form of permanent long-term memory; this will here be termed the *internal lexicon* (see Coltheart 1978; Coltheart *et al.* 1978). An individual word is represented in this lexicon as a *lexical entry*. To understand a printed word one must gain access to its lexical entry. Clearly this process, lexical access, must proceed regardless of the particular visual form of the printed word: the lexical entry for 'tree' must be accessible from TREE, tree, handwritten forms of the word, and so on. It would be chaotic to have different lexical entries for different visual representations of the same word. However, if the same entry is accessed by a variety of visual forms, the lexical access process itself provides no information about the particular visual form of the word whose lexical entry is accessed. How then, when presented with (STEEL mouse), do we know that 'STEEL' was in capitals and 'mouse' in lower case? This difficulty can be described in terms of the distinction drawn by Tulving (1972) between semantic memory and episodic memory. Semantic memory is memory for facts about the world (such as the meaning of the word 'tree'). Episodic memory is memory for events that have happened to us (such as seeing a pair of words a few lines above, one in capitals and one in lower case). The difficulty to which I am drawing attention here is the coordination of semantic memory with episodic memory. Semantic memory tells us that one of (STEEL mouse) is a metal and the other an animal. Episodic memory tells us that what we saw was a word in capitals and one in lower case. What tells us that the metal was printed in capitals and the animal in lower case?

Presumably, in some way impossible to envisage at present, episodic information becomes temporarily attached to a lexical entry. If this temporary episodic information is subject to rapid decay when it has been obtained hurriedly from a brief display, then perhaps iconic memory consists of the attachment of episodic information to a lexical entry.

## Conclusions

I began by distinguishing three senses in which one might say that vision persists. There is visible persistence: visual stimuli continue to be visible for some time after their physical offset. There is neural persistence: at various stages in the visual system, neural activity evoked by a stimulus continues to occur for some time after stimulus offset. There is informational persistence ('iconic memory'): the sensory information contained in a visual display remains available to an observer for some time after stimulus offset. The relation between these three persistences of vision has not been established. It has sometimes been claimed that all three are manifestations of a single process looked at from three different perspectives.

I have proposed that visible persistence is in fact the phenomenological correlate of neural persistence (in fact, of neural persistences, since persistences at the level of the receptor potential, the ganglion cell, and the stereopsis system may all generate forms of visible persistence). Iconic memory is another matter. There are reasons for rejecting an identification of iconic memory with visible persistence. There are also reasons for rejecting an identification of iconic memory with neural persistence, at least at the retinal level. The nature of iconic memory thus remains obscure. A possibility is that iconic memory, rather than representing an early stage in the information-processing sequence (a peripheral sensory buffer store), arises at a very late stage, after stimulus identification. To develop this possibility into a theory, it will be necessary to explain how episodic and semantic information about a stimulus may be coordinated. This is at present beyond the capabilities of cognitive psychology; it is the fundamental question for the psychology of perception.

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