

OBSERVATIONS

Is the Icon's Worth Apples and Oranges? Some Fruitful Thoughts on Loftus, Duncan, and Gehrig (1992)

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Iconic memory, initially a unitary concept, was later reclassified into a multidimensional concept comprising several distinct processing events associated with the perception of brief stimuli. With respect to partial-report performance, multidimensionality was demanded by two findings: the interstimulus interval (ISI) effect (a progressive decrement in performance as the ISI is increased), and the inverse-duration effect (a progressive decrement in performance as stimulus duration is increased). Loftus, Duncan, and Gehrig (1992) suggested that both effects may be explained by a single set of principles. It is shown that given a stimulus of long duration, their model may be made to account for either the ISI effect or the inverse-duration effect, but not both. It is concluded that a unidimensional concept of the icon cannot account for this and similar evidence and is inconsistent with the outcomes of neuroanatomical and neurophysiological studies of visual functioning.

In the beginning was the icon (Neisser, 1967). And the icon was generally assumed to be a unitary—albeit short-lived—representation lingering within the visual system after the termination of the display. Decay of the icon was said to begin upon stimulus termination, much as the charge of a leaky capacitor begins to drain when the voltage source is disconnected, or as an image projected on a screen begins to fade when the light source is dimmed.

Although plausible at first, the assumption of unidimensionality was disconfirmed by later findings. Contrary to expectations based on a unitary hypothesis, not all attributes of the icon were found to follow the same rules, and not all of its informational components were found to have similar decay functions. For example, it has been firmly established that the decay of information about the location of an item follows a time course substantially different from that of the decaying information about the identity of that item (Irwin & Yeomans, 1986; Townsend, 1973). In a similar vein, it has been established that different rules govern the decay of visible and nonvisible attributes (Coltheart, 1980; Di Lollo, 1980; Phillips, 1974).

To account for these and similar findings, the unitary conception of the icon was abandoned in favor of alternative

schemes, all multidimensional. Sperling (1967) proposed a subdivision in terms of visible and nonvisible memory traces; Phillips (1974), Turvey (1978), and Dixon and Di Lollo (1991) distinguished visible from schematic persistence; Coltheart (1980), Irwin and Yeomans (1986), and Di Lollo and Dixon (1988) separated visible from informational persistence. In every scheme (more have been suggested), iconic memory was reclassified into two or more components, each governed by different rules and affected by different variables.

Bucking the multidimensional tide, Loftus and colleagues (Loftus, Duncan, & Gehrig, 1992; Loftus & Hanna, 1989; Loftus & Hogden, 1988; Loftus, Johnson, & Shimamura, 1985) put forward a theory of iconic memory based on the premise of a unitary icon. The major tenets of the theory are summarized and elaborated in the article that is the object of the present comments (Loftus, Duncan, & Gehrig, 1992). In that article, Loftus et al. reiterated that the icon is unidimensional and that its duration is constant and unaffected by such variables as the duration of the inducing stimulus. The spirit of the theory is captured with pith and conciseness as follows: "[T]here is only a single iconic-decay function that is tacked onto the end of the stimulus-present function, independent of stimulus duration" (Loftus et al., 1992, p. 545).

Despite its parsimony, we believe that this conception of the icon is untenable because it is at odds with the experimental evidence. The problem can be outlined most clearly with reference to two well-known effects: the ISI (interstimulus interval) effect, and the inverse-duration effect. The ISI effect refers to the progressive decrement in partial-report performance as the ISI between stimulus termination and probe onset is increased (e.g., Sperling, 1967). The second effect is best described in terms of a temporal integration task wherein two sequential stimuli must be integrated perceptually in order to form a single meaningful pattern. Because the two stimuli do not overlap in time, integration must take place between the second stimulus and the sensory traces (or sensory persistence) of the first. The greater the persistence of the first stimulus,

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the better the integration. When performance in such an experiment is examined as a function of duration of the first stimulus, a counterintuitive outcome is obtained: Goodness of temporal integration—and hence level of performance—diminishes as stimulus duration is increased (e.g., Bowen, Pola, & Matin, 1974; Di Lollo, 1980; Efron, 1970). This effect has come to be known as the “inverse duration effect” (Coltheart, 1980). An important consideration in the present context is that both the ISI effect and the inverse-duration effect can be found in partial-report experiments (e.g., Di Lollo & Dixon, 1988; Dixon & Di Lollo, 1991).

To summarize, accuracy of partial-report performance can be impaired in at least two ways: by increasing the exposure duration of the stimulus array and by increasing the duration of the ISI. We submit that the two effects have different underlying mechanisms, each operating according to different principles that are encompassed naturally within a multidimensional model such as the one outlined in the next section. We further submit that it is problematical to account for both effects with the same set of principles within a unidimensional model such as that proposed by Loftus.

A Multidimensional Approach

We believe that the experimental evidence (reviewed by Coltheart, 1980) that forced the abandonment of a unitary model of the icon over a decade ago is still trenchant today. To account for this evidence, we have suggested that iconic memory is made up of at least two types of persistence: One (*visible persistence*) is time-locked to the onset of the inducing stimulus and decays as a function of time elapsed since stimulus onset. Whether two sequential stimuli can be perceptually integrated on the basis of visible persistence (as in the example outlined in the previous section) will depend on the stimulus onset asynchrony (SOA, the time elapsed between the onset of the first stimulus and the onset of the second). Because decay is held to begin shortly after stimulus onset, the strength of visible persistence at stimulus offset is inversely related to stimulus duration. This account of the inverse duration effect is buttressed by neurophysiological recordings from the cat's visual cortex, which show the activity of specific single units to be time-locked to stimulus onset and to last for a fixed period regardless of stimulus duration (Duysens, Orban, Cremieux, & Maes, 1985).

Besides visible persistence, we have proposed a second, independent form of labile memory, which we have referred to as *schematic persistence* (Di Lollo & Dixon, 1988; Dixon & Di Lollo, 1991). Although not necessarily visible, schematic persistence maintains a representation of the display for a brief interval. In addition, schematic persistence is held to be time-locked to the termination of the physical display and to be unaffected by stimulus duration.

The independence of the two sources of information must be stressed. Independence, in this case, means that each contributes to performance even if there is no residual information in the other source. Thus, one may be able to perform the partial-report task on the basis of schematic persistence even if there is no residual information in visible persistence. Formally, performance is determined by what is essentially the sum of two decay functions.

Loftus's Unitary Approach

Loftus and his coworkers have raised the intriguing possibility that both the ISI effect and the inverse-duration effect can be explained using a single set of principles within a unidimensional model. The account of the ISI effect is straightforward: All information contained in the stimulus array is held to remain available while the stimulus remains on view and to decay upon stimulus termination at a rate indexed by a function $b(t)$. This is similar to schematic, or informational, persistence in our model in that both decay functions are time-locked to stimulus offset. Because of this decay of information, both models predict that partial-report performance will decrease as the ISI between stimulus array and probe is increased.

Loftus's account of the inverse-duration effect is presented only in broad outline in the target article but is described in detail in an earlier publication (Loftus & Hanna, 1989). That account is summarized in succeeding paragraphs, but first it is necessary to outline some basic concepts essential to Loftus's explanation of the effect. The explanation hinges on $r(t)$, the rate of information extraction from the stimulus array. As is visible persistence in our model, $r(t)$ is time-locked to the onset of the display. The assumption is made that $r(t)$ decays as the amount of yet-to-be-extracted information is reduced. After stimulus offset, $r(t)$ decays at a faster rate because the representation (the “icon”) from which the information is being extracted is itself decaying at a rate indexed by $b(t)$.

It is assumed that, at the time of stimulus offset, the information indexed by $b(t)$ comprises all of the information contained in the stimulus regardless of exposure duration. However, this information is only potentially available for supporting performance in such tasks as partial report. In order to become useful, information must be extracted from the decaying store. Just how much information can be extracted will depend on the information-extraction rate, $r(t)$. Thus, although it is true that $b(t)$ corresponds roughly to schematic persistence in our model, it does not contribute to performance directly. Rather, $b(t)$ affects performance indirectly through its interaction with $r(t)$.

In accounting for the inverse-duration effect, Loftus and Hanna (1989) reasoned as follows. Performance in a partial-report experiment depends primarily on the information extracted from the stimulus array after the probe has been presented. This, in turn, depends on the rate of information extraction, $r(t)$. More specifically, the total amount of information extracted can be found by integrating $r(t)$ from the time of probe presentation onward. This can be readily illustrated with reference to Figure 1. Assume that the ISI is equal to zero, so that the probe is presented at the time of stimulus offset. Then the amount of postprobe extracted information (and hence the accuracy of partial-report performance) will correspond to the area under the curve from the time of stimulus offset onward. In Figure 1, Panel A, the total shaded area represents the postprobe extracted information for a stimulus duration of 10 ms; the much smaller total shaded area in Panel B corresponds to the information extracted after a stimulus of 200 ms. Clearly, the accuracy of partial-report performance decreases as stimulus duration is increased, as might be expected on the basis of the inverse-duration effect.

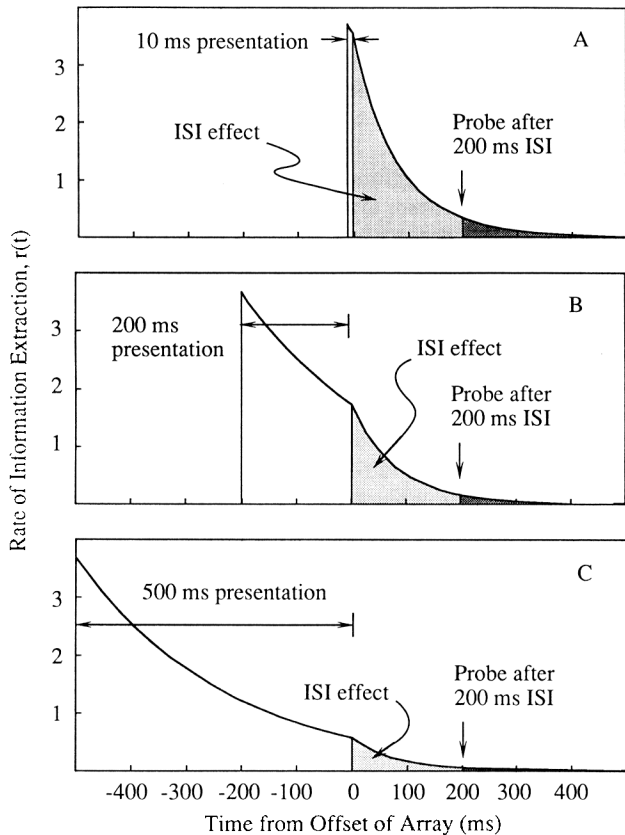


Figure 1. Illustration of the effect of introducing an interstimulus interval (ISI) according to Loftus (Loftus & Hanna, 1989; Loftus et al., 1992). (The curves indicate the amount of information extracted after an ISI of 200 ms with stimulus durations of 10 ms [Panel A], 200 ms [Panel B], or 500 ms [Panel C]. The magnitude of the ISI effect is represented by the lightly shaded areas; the amount of extracted information is represented by the darkly shaded areas; the amount of information that would be extracted if the ISI was equal to zero is represented by the total shaded areas in each panel.)

Implications of Loftus's Account

Unquestionably, these tenets are successful in predicting an inverse-duration effect as well as an ISI effect. However, it can be shown that the same tenets make it impossible to predict a substantial ISI effect following a stimulus array of long duration. Recall that, according to Loftus (Loftus & Hanna, 1989; Loftus et al., 1992), partial-report performance depends on the amount of information extracted after the probe has been presented. This, in turn, depends on the integral of $r(t)$ from the time of probe presentation onward. Let us now consider the effect of introducing an ISI in the display sequence. If the ISI is introduced when $r(t)$ is high (i.e., after a brief stimulus), its detrimental effect on performance will be notable because, during the ISI, $r(t)$ will decay very rapidly. The effect on performance will correspond to the amount of information that might have been extracted from the array had there been no ISI. This corresponds to the area under the $r(t)$ curve spanned by the duration of the ISI.

Figure 1 illustrates this effect. The curves in Figure 1 are similar to those in Figure 13 of Loftus and Hanna (1989) and

were calculated from the parameter values used by Loftus and Hanna to predict the inverse-duration effect found by Di Lollo and Dixon (1988). The three panels in Figure 1 illustrate the decreasing magnitude of the ISI effect as stimulus duration is increased from 10 ms (Panel A) to 500 ms (Panel C). After a 10-ms stimulus, the ISI effect is large because $r(t)$ decreases substantially during the ISI. By contrast, after a 500-ms stimulus, the decay of $r(t)$ is correspondingly smaller, and so is the size of the ISI effect. In general, as stimulus duration becomes very long, the magnitude of the ISI effect becomes vanishingly small.

To summarize the implications of Loftus's theory, it is clear that a large ISI effect is predicted if the leading stimulus is brief, but not if it is long. By contrast, according to a multi-dimensional model such as ours, a substantial ISI effect should be obtained even after long exposure durations. This is so because schematic persistence—which underlies the ISI effect—is held to be independent from visible persistence and to be unaffected by stimulus duration. This difference between the two models permits the following empirical test.

An Empirical Test

Imagine a partial-report experiment in which an array of alphabetical characters is followed immediately by a bar-probe that singles out the character to be reported. Given a long-duration array, the introduction of an ISI before the onset of the probe should have a negligible effect on performance according to Loftus's model, but a significant effect according to ours.

A potential problem in designing such an experiment lies in selecting a suitable exposure duration so as to ensure that rate of information extraction, $r(t)$, is at a minimum before the stimulus is turned off. We decided that the safest strategy was to determine the critical duration empirically. In preliminary trials, we displayed a letter array of progressively longer durations, followed immediately by the probe (ISI = 0). As expected on the basis of both models, performance decreased as the duration of the array was increased, but the decrements became asymptotic at array durations well short of 500 ms. Increasing the duration to 1,000 ms produced negligible changes in performance. As noted earlier, this leads to the theoretical expectation that the introduction of a brief ISI after the 500-ms stimulus (or after the 1,000-ms stimulus) should have minimal, if any, effects on performance.

By contrast, our model predicts that performance should drop substantially during the first 100 or 200 ms of the ISI as schematic persistence decays. Furthermore, given asymptotic performance (indicating that the onset-locked visible persistence has vanished), the effect of ISI on performance should be invariant with array duration. This follows from the assertion that the magnitude of schematic persistence is independent of stimulus duration.

Stimuli and procedures were similar to those described by Di Lollo and Dixon (1988). In brief, 15 uppercase alphabetical characters, drawn randomly without replacement from the set of 26, were displayed around the periphery of an imaginary circle (6° in diameter) on an oscilloscopic point-plotter (Tektronix 608, equipped with fast P15 phosphor). The probe was a radial line of 10 ms duration, 1° in length, terminating 0.5°

away from the cued character. Observers maintained fixation on a point in the center of the display, pressed a button to generate a stimulus sequence, and named (or guessed) the probed letter over an intercom to the experimenter, who entered it on a computer keyboard. Each of 5 observers served in nine experimental sessions, one for each factorial combination of three durations of the letter array (10, 500, and 1,000 ms) and three ISIs (0, 100, and 200 ms). All stimuli were displayed so as to appear equally bright on the screen. To this end, the 10-ms stimuli were displayed at a higher nominal luminance than the two longer stimuli, which had identical luminance. Note that although brightness-compensation procedures make it possible to use stimuli of very brief durations (which would otherwise be barely visible), they are not necessary for obtaining a strong and temporally substantial inverse-duration effect (e.g., Bowen et al., 1974; Efron, 1970). Each session consisted of 100 trials.

Individual results are illustrated in the upper five panels of Figure 2 and are represented quite faithfully by the averaged results summarized in the lower left panel labeled "Means A" and replotted with ISI as the parameter in the panel labeled "Means B."

Consider the results for ISI = 0 in the "Means A" panel of Figure 2. Level of performance shows a drop of almost 30% as array duration is increased from 10 ms to 500 ms, but it

remains virtually unchanged with a further increment to 1,000 ms. The asymptotic performance beyond 500 ms is illustrated more clearly by the 0-ms curve in the "Means B" panel. The drop (inverse-duration effect) as well as the asymptote are predicted by both models. Loftus's model explains the drop in terms of reduced $r(t)$, reflecting the declining rate of information extraction as the amount of yet-to-be-extracted information diminishes. In our model, the drop reflects the decay of visible persistence with increasing SOA. As for the asymptotic performance beyond 500 ms, in Loftus's model it simply means that the rate of information extraction, $r(t)$, has reached an asymptotic minimum. Under these conditions, as we noted earlier, the introduction of a brief ISI before the onset of the probe should have a negligible effect according to Loftus's theory. To be specific, the two lower curves in the "Means A" panel of Figure 2 should remain virtually flat throughout the domain. But this is clearly not the case. For array durations of 500 ms and 1,000 ms, mean performance declined by over 20% as the ISI was increased from 0 to 200 ms. This result is inexplicable in terms of Loftus's unidimensional model as presently stated, but it is explained naturally in terms of decaying schematic persistence over the period of the ISI.

Admittedly, it could be argued that a multidimensional model such as ours (Di Lollo & Dixon, 1988; Dixon & Di

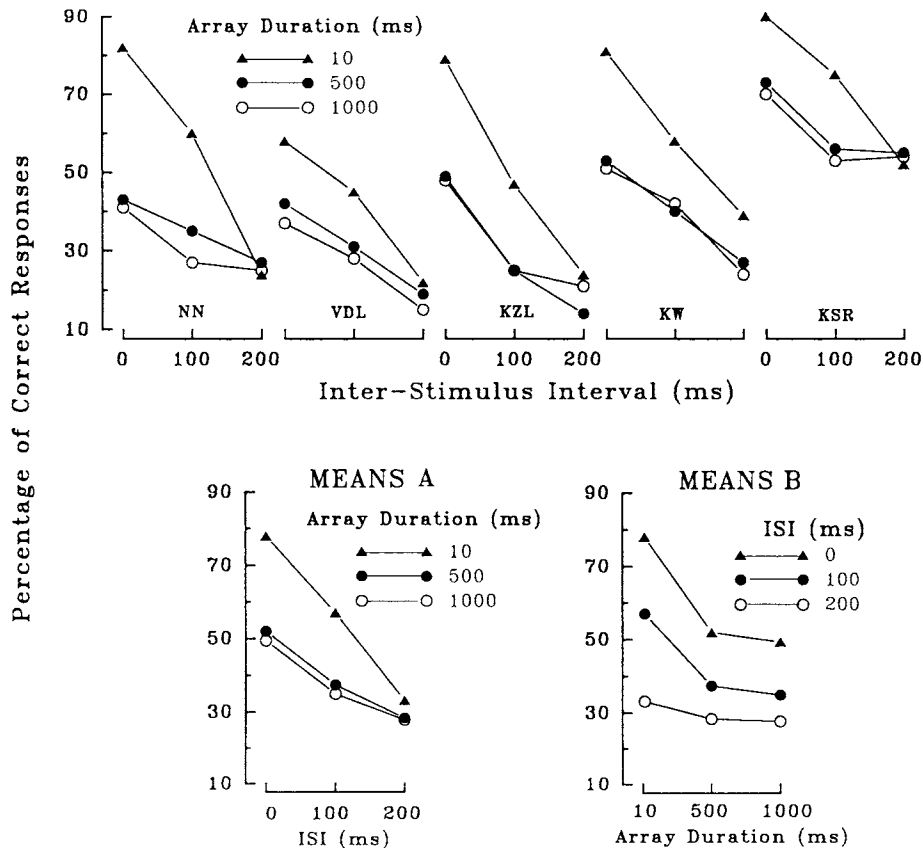


Figure 2. Percentage of correct responses in relation to exposure duration of the array of 15 alphabetical characters and delay (interstimulus interval or ISI) of the bar-probe in the partial-report task. (The upper panels display the individual results separately for each of the 5 observers. The lower panels show the mean results with array duration as a parameter [A] and with ISI as a parameter [B].)

Lollo, 1991) should be expected to account for a greater proportion of the variance than any corresponding unidimensional model (e.g., Loftus & Hanna, 1989; Loftus et al., 1985; Loftus et al., 1992) simply because the additional factor must account for at least some of the variance, even if only error variance. However, this can hardly be said of the present experiment: A drop in performance of over 20% must be regarded as substantial, and its strict temporal dependence on the termination of the display puts it beyond what could be plausibly regarded as a chance occurrence.

In the face of this and allied evidence (Coltheart, 1980), the conclusion is inescapable that Loftus's unidimensional theory does not provide an adequate account of the range of phenomena connoted by the term *iconic memory*. The problem appears to lie with the model's unidimensionality or, more specifically, with the interdependence between $r(t)$ and $b(t)$. If, as is the case in its present version, the model is couched so as to account for the inverse-duration effect, it fails to account for the ISI effect after long-lasting stimuli. On the other hand, the theory *could* explain the ISI effect if extraction rate were independent of stimulus duration. This was precisely the case in an earlier version of the theory (Loftus & Hogden, 1988) based on the twin assumptions that information does not decay until stimulus offset and that extraction of information does not begin until the probe is presented. However, that version of the theory could not account for the inverse-duration effect because neither available information nor rate of extraction were affected by stimulus duration. Indeed, the later model of Loftus and Hanna (1989) was designed to remedy this shortcoming. But the upshot was not entirely successful: Although capable of accounting for the inverse-duration effect, the new model failed to account for the ISI effect after long stimuli, as we have seen. To say it with the ancients, if the helmsman steers clear of Scylla he falls prey to Charybdis.

This is not to say that some new version of Loftus's theory might not succeed in accounting for both effects using a single set of rules within a unidimensional framework. Indeed, we ourselves have made informal attempts at doing just that. But our attempts invariably resulted in models that were, in some salient way, multidimensional.

On Encoding, Information, and Memory Representations

The inability of Loftus's model to account for some of the critical evidence regarding iconic memory is not to be ascribed to the model's mathematical implementation. Rather, the source of the problem is to be sought in the conceptual framework of the model itself, particularly in the assumption of unidimensionality. To be sure, even while promoting a unitary theory, Loftus acknowledged that the notion is intuitively implausible: The representation of a complex stimulus is unlikely to be unidimensional (Loftus et al., 1992). Indeed, Loftus pointed to alternative models that have opted for a multidimensional icon on the grounds that the processing activities related to different attributes of the stimulus (its location, identity, etc.) seem to produce persistence of different durations (e.g., Irwin & Yeomans, 1986). However, the

issue is finessed by asserting that the magnitude of the icon is best conceived as being determined globally (i.e., in terms of the total information extracted from the stimulus) rather than severally (i.e., in terms of the distinct memory representations of separate stimulus attributes). Clearly, Loftus acknowledged the likelihood that different attributes of the stimulus may have separate memory representations. But he also maintained that the icon is based on the total information contained in all of the separate representations and that such information is unidimensional:

Suppose that there are J relevant memory dimensions (e.g., in a model positing item and location information, $J = 2$). At time t following stimulus onset, the memorial representation of the stimulus can be represented by a point in J -dimensional stimulus space. *Encoding* consists of the point's movement along some path through the space, and *information* can be defined as the distance traversed along this path. By this definition, *information* is unidimensional, whereas the *memory representation* is multidimensional. (Loftus et al., 1992, p. 533, italics in original)

The crucial assumption of this definition (and its major weakness) is that for the purpose of defining the icon, the specific nature of the encoding activity is held to be irrelevant. In other words, information based on the activity of, say, color analyzers is regarded as equivalent to information based on, say, form analyzers or to information related to the abstract identity of an item.

We regard this as an unlikely scenario. There is compelling evidence that different visual functions such as color, form, depth, and motion are processed in anatomically separate pathways that differ significantly from one another in temporal and spatial properties (Livingstone & Hubel, 1987, 1988). In view of qualitative differences and temporal asynchronies among pathways, it seems implausible that information based on activity in one such subsystem is functionally equivalent to that in another. For example (with reference to the preceding quote from Loftus et al., 1992), at time t , processing activity related to an item's spatial location may have subsided and hence will no longer be part of the information contained in the icon. At the same time, information regarding the item's identity may still be abundantly available (as shown by Townsend, 1973, and by Irwin & Yeomans, 1986, among others). In this case, the icon's effectiveness in mediating performance before or after time t will vary greatly, depending on whether the experimental task requires location or identity information. Similarly, as we showed in the empirical test reported here, information arising from processing activities at the onset and at the termination of a stimulus can hardly be regarded as functionally equivalent. These considerations strongly suggest a multidimensional icon whose various attributes decay at different rates.

Despite its parsimony, unidimensionality of the icon seems to be a difficult principle to maintain, practically and conceptually. Perhaps, in an extended sense, Loftus may be correct in saying that the processing activities corresponding to the various visual functions (color, form, spatial location, and emerging identity) can all be subsumed under the rubric of "information." But this is the same sense in which apples and oranges can both be subsumed under the rubric of "fruit."

And we must not forget that if we set out to make an apple pie, just what fruit it is we select may be crucial to the outcome.

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