Is visual information integrated across saccades?

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After subjects established fixation on a target cross, 12 dots were presented parafoveally. When the dots were presented, the subjects made an eye movement to the location of the dots, and during the saccade the 12 initially presented dots were replaced by 12 other dots. The 24 dots were part of a 5 × 5 matrix, and the task of the subject was to report which dot was missing. The data were consistent with other recent studies: subjects could successfully report the location of the missing dot far above chance (54%), whereas performance in a control condition (in which the two sets of dots were presented to different spatial and retinal locations) was almost at chance level (10%). However, a number of control conditions demonstrated that the effect was due primarily to persistence from the phosphor of the cathode ray tube used for stimulus presentation and that little of the visual information integrated was across two fixations. Implications of the results for a theory of integration across saccades are discussed.

One of the most fascinating aspects of visual perception is that we perceive a stable visual world despite the fact that we make discrete eye movements every 250-300 msec, on the average (Rayner, 1978a). Although the retina is moved across the visual world every fourth of a second, we do not perceive quick snapshots, of the scene in front of our eyes, separated by blurs from the eye movements. The question of how the brain is able to integrate the information from successive eye fixations is largely unanswered. In fact, most of the research on visual information processing has avoided this question by employing brief stimulus presentations that are seen on a single fixation and are thought to simulate what happens on a single presentation of a visual stimulus viewed naturally. Recent technological advances, however, have made it possible to vary precisely the characteristics of information available to the subject on successive fixations (Ikeda & Saida, 1978; McConkie & Rayner, 1975; Rayner & Bertera, 1979). Such a technique was used in the experiments reported here to investigate how information is integrated across saccades.

One simple way in which information could be combined across saccades is via a memory buffer in which information from the same spatial coordinates, but different retinal coordinates, is appropriately aligned. On the basis of experiments

(McConkie & Rayner, 1975; Rayner, 1975; Rayner & McConkie, 1976) on eye movements and the perceptual span in reading, McConkie and Rayner (1976) hypothesized such a buffer, which they termed an *integrative visual buffer*. The integrative visual buffer is thought of as a retina-like store (Trehub, 1977, uses the term "retinoid") in the brain in which visual information is stored point by point as a two-dimensional projection of the three-dimensional image being viewed. According to McConkie and Rayner, information obtained from parafoveal vision on fixation n is held in the integrative visual buffer and combined with information available in foveal vision on fixation n + 1 following a saccade. The justification or alignment of information in the buffer was assumed to be based upon two processes. First, the subject keeps track (at an unconscious level) of how far the eyes move, and second, visual elements sharing common features are aligned together. By such a process, stimuli would not only be identified more rapidly, but we would also perceive a stable and coherent world. However, most formulations of the model have not specified either the decay constants of storage in the buffer or the mechanism by which the imprecise image from the parafovea on one fixation is combined with the precise image from the fovea on a later fixation.

Unfortunately, the results of a number of studies (Levy-Schoen & O'Regan, 1980; McConkie & Zola, 1979; Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980; Pollatsek, Rayner, & Collins, Note 1) with meaningful stimuli (words or line drawings) have failed to find any evidence consistent with the integrative visual buffer hypothesis. In the paradigm developed by Rayner (1978b), subjects were asked to fixate a target cross and were

then shown a letter string in parafoveal vision. When the parafoveal string appeared, the subjects made an eye movement to that location. During the saccade, the initially displayed string was replaced by a word, which the subject was asked to pronounce as quickly as possible.[1] The visual similarity between the initially displayed stimulus and the word the subject named was varied, as was the distance from fixation at which the first string was displayed. Although there was facilitation in naming the word when the parafoveally presented string had the same beginning two or three letters, the general pattern of results indicated that subjects were not combining visual information across saccades as implied by the integrative visual buffer hypothesis. First, Rayner et al. (1978) found that the same pattern of results was obtained when the subject made an eye movement and when the saccade was simulated, although the effect was somewhat smaller when the saccade was simulated. In the simulation condition, before the word to be named was presented in foveal vision, the parafoveal string was displayed for a period of time approximating the latency of a saccade. In both the eye-movement condition and the simulation condition, the sequence of events on the retina was identical: a parafoveal stimulus impinged on the retina first; this was followed by a foveal stimulus. In the eye-movement condition, an eye movement intervened between the two events, whereas in the simulation condition, the stimulus was displaced across the visual field. Since the same pattern of results was obtained in the two conditions, the experiment indicates that either (1) subjects were integrating visual information across saccades, but the stimulus being in the same spatial position was not important for justification of the image, or (2) the information was being integrated at a more abstract level, one at which spatial position is not crucial for integration. In either case, the data are problematic for the integrative visual buffer hypothesis.

A second, and more damaging, finding concerning the integrative visual buffer hypothesis was that changing the case of letters in the word during the saccade had no effect upon the pattern of results (Rayner et al., 1980). In fact, McConkie and Zola (1979) asked subjects to read text that was presented in alternating case so that each time the eye moved, every letter on the line of text changed shape. Thus, "dIsPlAy" on fixation n would become "DiSpLaY" on fixation n+1 and then return to the other version on the next saccade, alternating back and forth between the two versions. Not only did this manipulation have no effect on reading performance, but the subjects were not aware that the change was taking place. Presumably, if subjects were overlapping visual information in a buffer, then changing the case of every letter should disrupt reading and affect the subject's percept. Rayner et al. (1980) were able to demonstrate that the facilitation obtained in the task was due to preliminary letter processing of the first two or three letters of the parafoveal string. Thus, when the initial two or three letters of the initially displayed parafoveal string were consistent with the word to be named, facilitation occurred. Rayner et al. (1980) argued that the facilitation was due to preliminary letter processing of the parafoveal word and that an abstract code (independent of the case in which the letters were presented) was responsible for the facilitation. In any case, the results of the experiments clearly indicated that the information integrated from fixation to fixation was not visual.

The general conclusion that visual information is not integrated from fixation to fixation in the point by point manner of the integrated visual buffer is also supported by recent experiments by Pollatsek et al. (Note 1), which were pictorial analogues of the experiments conducted by Rayner and his colleagues with words. In the Pollatsek et al. experiments, subjects looked at a fixation cross and a line drawing of an object was presented parafoveally. The subjects made an eye movement to the location of the picture, and during the saccade the picture either remained the same or changed to a drawing of another object. Pollatsek et al. found that a parafoveal glimpse of the stimulus prior to the saccade facilitated naming the object. However, they found that if the form was kept constant, an equally large facilitation effect was observed when the line drawing changed in size during the saccade (the drawing became either larger or smaller). Another experiment showed that a line drawing with the same form (with or without size change) facilitated naming more than did a different drawing of the same concept, suggesting that some visual information was being integrated across saccades. However, the fact that the size change was irrelevant demonstrated that the level of integration was more abstract than that postulated for the integrative visual buffer.

In contrast with the above experiments, which utilized meaningful stimuli, a number of recent experiments using psychophysical stimuli have suggested that there is some visual integration across saccades. Wolf, Hauske, and Lupp (1978, 1980) found a threshold decrease for postsaccadic test patterns of medium spatial frequency exposed at a target location under conditions in which a presaccadic grating that had the same spatial frequency and the same spatial coordinate (but due to the intervening eye movement, different retinal coordinates) was presented to the subject. Ritter (1976) presented a parafoveal test pattern for 10 msec just prior to a saccade and a second 10 msec presentation following the saccade. He varied the ISI between the two stimuli and found that the critical ISI necessary to perceive two flashes was identical in both a fixation condition (no eye movement) and an eye-

movement condition. Wolf et al. and Ritter suggested that their results provided evidence that there is integration of visual information obtained from parafoveal regions with later information obtained in the fovea following a saccade. More recently, Breitmeyer (1983), Breitmeyer, Kropfl, and Julesz (1982), and Jonides, Irwin, and Yantis (1982), have reported psychophysical experiments which they suggest are consistent with the integrative visual buffer hypothesis.

Jonides et al. (1982) used an experimental task modeled after one used by DiLollo (1977, 1980; DiLollo & Wilson, 1978; Hogben & DiLollo, 1974) to study temporal integration. DiLollo's task required subjects to locate a missing dot in a 5 × 5 matrix. The 24 dots that were included in the matrix were presented in two frames of time. In the first, a randomly selected 12 dots were shown, and then, after a brief interval, a different set of 12 dots was shown at the same location. In order to localize the missing dot, the subject had to integrate (at some level) the two separate frames into a single representation of the matrix. Jonides et al. presented 12 dots to the right of fixation and subjects were instructed to make an eye movement to the location of the array. During the saccade, the 12 dots originally displayed were replaced by 12 other dots in different spatial locations. As in DiLollo's experiments, the 24 dots were from a 5 × 5 matrix and the subjects' task was to report which dot was missing.

Jonides et al. found that subjects could make the judgment correctly over 50% of the time. Given that chance performance was 4%, the result is quite impressive. Furthermore, a control condition was run in which the initial 12 dots were presented parafoveally and, after a period of time approximating the latency of the saccade, the second 12 dots appeared in foveal vision. Performance in the control condition was only 6%. This control condition is analogous to the simulated eye-movement condition of the Rayner et al. (1978) experiments. However, the general pattern of results was quite different from that found by Rayner et al. (1978), since, in the latter study, the facilitating effect of the first stimulus was affected little by whether or not it was in the same spatial location as the second stimulus. The experiment by Jonides et al. (1982) is supported by the results of very similar experiments reported by Breitmeyer et al. (1982). Breitmeyer et al. used a 4 × 4 matrix rather than a 5 × 5 matrix, and the task was somewhat different. On 50% of the trials, 15 of the 16 dots were presented (eight on the first fixation and seven on the second fixation, for example), and on the other 50% of the trials, all 16 dots were presented. The subjects' task on each trial was to determine if a dot was missing. In the experimental condition, the first array was shown parafoveally, and when the subject made an eye movement, the second array was presented foveally. Thus, the stimuli were presented in the same spatial location but different retinal locations. In this condition, subjects were accurate 71% of the time (chance equals 50%). In two control conditions, subjects performed no better than chance. In the first control condition, similar to that of Jonides et al., the subject maintained fixation and the first array was presented parafoveally and the second foveally. In the second control condition, the two arrays were both presented to the fovea, but with an intervening eye movement so that the stimuli appeared in the same retinal location but in different spatial locations. Performance was 51% and 49% in the first and second control conditions, respectively.

On the basis of their results, Breitmeyer (1983) and Jonides et al. (1982) have suggested that the idea of an integrative visual buffer in which visual information is overlapped in a point-to-point manner should be resurrected. If these experiments do demonstrate such a visual buffer, then one is faced with the task of explaining why no evidence was obtained for it in the reading and picture processing experiments. One way to explain the differences in results between the experiments utilizing meaningful stimuli and those reported by Breitmeyer et al. (1982) and Jonides et al. (1982) is to assume that, with simple stimuli, visual information is integrated across saccades, but that, with meaningful stimuli, non-visual variables are more important and may even suppress lower level visual information. Alternatively, different types of information could be integrated in different tasks and those in which visual information is important could yield results indicating that visual information is combined across saccades. However, prior to appealing to more complex types of processes to account for the differences, a first priority seems to be to examine the procedures of the Breitmeyer et al. and Jonides et al. studies more critically to determine if there are potential artifacts associated with each that could account for the pattern of results they obtained.

In the case of the Breitmeyer et al. experiment, the decision to present only eight or seven dots on each fixation presents a problem. Since the span of immediate memory is just barely exceeded, above-chance performance is quite plausibly mediated by an abstract short-term representation of the first set of dots rather than a visual memory. It is also unfortunate that eye movements were not monitored in their experiment. Breitmeyer (1983) argued that monitoring of eye movements was not critical in the task, yet, given the considerable variability that exists in eye-movement latencies for a single subject, it would seem important to know exactly when the eye moved with respect to the stimulus presentations. In the Breitmeyer et al. experiment, the first stimulus was presented for 200 msec and followed,

40 msec later, by the presentation of the second stimulus for 20 msec. If the eye movement was executed with a latency of around 150 msec, subjects would get a clear foveal view of both sets of dots and would be responding as in the DiLollo experiment, which says nothing about integrating information across eye movements. Jonides et al. did monitor eye movements in the task, but a more serious problem exists in their experiment, as it does in the Breitmeyer et al. experiment and in the Wolf et al. (1978, 1980) experiments cited earlier. A cathode ray tube (CRT) was used to present the stimuli in all of these experiments, and there appears to be no guarantee that the results were not due to persistence on the screen. Jonides et al. used a CRT with a P-4 phosphor, while Breitmeyer et al. and Wolf et al. used a CRT with a P-31 phosphor. Although both of these phosphors are known to have fast decay rates and both decay to 1% of maximum brightness in microseconds, the remaining persistence decays much more slowly over a period extending up to a second or so. Given these facts about CRT phosphors, we believed it would be reasonable to replicate the experiments using various control conditions to assess the contribution of screen persistence to the phenomenon observed by Breitmeyer et al. and Jonides et al. Under conditions that are very similar to those employed in the Jonides et al. experiment, we were able to replicate their basic finding. However, a number of control conditions that we included shed serious doubts on the general conclusions they reached.

METHOD

Subjects

Four members of the University of Massachusetts community participated in the experiments. Two of the subjects (A.I. and J.M.) were paid to participate and were naive with respect to the purposes of the experiments. The two authors served as the two other subjects. All of the subjects had normal vision and did not require corrective lenses for reading.

Apparatus and Procedure

Subjects looked at the face of a Hewlett-Packard CRT with a P-31 phosphor. The phosphor has the characteristic that it decays to 1% of maximum brightness in .25 msec. Head movements were eliminated by use of a bite bar, and eye movements were monitored via a Stanford Research Institute dual Purkinje eyetracker. Accuracy of the eyetracker is in the range of 10 min of arc. The eyetracker and the CRT were both interfaced with a Hewlett-Packard 2100 computer that was used to present the stimuli and to record eye-movement latencies and the accuracy of the judgment. The signal from the eyetracker was sampled every millisecond, and the position of the eye was determined every 4 msec. When the eye moved ½ deg in the appropriate direction, the appropriate display changes were initiated.

In the basic *visual integration* condition, the subjects were instructed to fixate a target cross presented in the center of the CRT. Upon successful fixation, the experimenter pushed a button that resulted in the presentation of 12 dots in parafoveal vision, beginning 2.67 deg to the right of fixation. When the subject made an eye movement, the computer replaced the 12 dots that were initially displayed with 12 other dots. The 24 dots

presented were part of a 5 × 5 matrix with one dot missing from the array, and subjects were asked to indicate the row and column location of the missing dot. The first 12 dots were thus presented for the latency of the eye movement, and the second 12 dots were presented for 20 msec following a 40-msec interval that ensured that the saccade had actually been completed before the 12 dots appeared.[2] The subject's eye was 46 cm from the CRT, and the entire 5 × 5 matrix extended 2.67 deg vertically and horizontally. Luminance on the CRT was adjusted for each subject at the beginning of a session and held constant throughout the session at approximately 8 cd/m². The data were collected in 6-8 sessions, each lasting approximately 1½-2 h with breaks whenever the subject desired. Each session began with one or two practice blocks of 32 trials, and conditions within a session were presented in a random manner, with 32 trials per block.

In the visual integration condition, the first and second stimuli were presented to the same spatial location but to different retinal locations. This condition was essentially the same as that used in both the Breitmeyer et al. and Jonides et al. studies. There were two *memory control* conditions, in which the information presented was the same as that presented in the visual integration condition with approximately the same timing, but in which the two sets of 12 dots appeared in different spatial locations (see Table 1). These conditions were run to test the hypothesis that integration was crucially dependent on the stimuli being fixed spatially during the saccade. In the *memory control A* condition (employed by Jonides et al.), the first 12 dots were presented parafoveally and, while the subject maintained fixation, the second 12 dots were presented foveally. The first stimulus was presented for a duration approximately equal to the average saccadic latency in the visual integration condition, and the delay between stimuli was 40 msec. Thus, in this condition, the retinal events of the visual integration condition were mimicked, but no eye movement intervened between stimuli and the stimuli were in different spatial locations. In the *memory control B* condition (adapted from Breitmeyer et al.), the first 12 dots were presented foveally, the subject moved his or her eyes to a parafoveal location, and then the second 12 dots were presented foveally in that location. The sequence of events was thus the same as that in the visual integration condition except that the first 12 dots were presented foveally. Thus, in the memory control A condition, the stimuli were both in different spatial and different retinal locations, whereas in the memory control B condition, they were in the same retinal locations but different spatial locations.

In addition, there were two important types of conditions employed to assess the effect of screen persistence on performance (see Table 1). The *persistence control* condition attempted to duplicate the screen persistence in the visual integration condition but eliminated the presentation of the first stimulus during the first fixation. The sequence of events was as follows. The subject fixated the center of the screen and then moved his or her eyes to the parafoveal location where the second 12 dots were presented. Near the beginning of the eye movement (i.e., when the eye crossed the threshold such that a saccade was judged to be in progress), the first 12 dots were presented once (taking less than 1 msec). The delay between the beginning of the eye movement and the presentation of the second set of 12 dots was 40 msec (as in the visual integration condition). Correct performance in this condition was thus dependent on the subjects' abilities to integrate the screen persistence of the first 12 dots with the second 12 dots.

The second kind of control condition attempted to mask the persistence. The *persistence mask* condition was identical to the visual integration condition except that a mask, consisting of all 25 dots, was presented during the saccade. Two variants of the condition were run. In the first (*persistence mask 1*), the 25 dots were pulsed once, and in the second (*persistence mask 5*), they were pulsed five times (within about 3 msec).

While the conditions described above were of primary interest, two subsidiary conditions were also employed. One surprising

Table 1
Conditions Employed in the Experiment

Condition Name	First Fixation*	Saccadic Events**	Second Fixation†
		Part A	
Visual Integration	12 dots in parafovea	1 extra pulse of first stimulus††	12 dots in fovea of same spatial location
Memory Control A	12 dots in parafovea	No saccade	12 dots in fovea at different spatial location (same fixation)
Persistence Control	No stimulus presented	1 pulse of 12 dots	12 dots in fovea at same spatial location
Persistence Mask 1	12 dots in parafovea	1 pulse of all 25 dots	12 dots in fovea at same spatial location
Foveal Integration	12 dots in fovea	No saccade	12 dots in fovea in same location (same fixation)
		Part B	
Memory Control B	12 dots in fovea	5 pulses of all 25 dots or nothing	12 dots in fovea at different spatial location
Persistence Mask 5	12 dots in parafovea	5 pulses of all 25 dots	12 dots in fovea at same spatial location

*The first stimulus was presented until an eye movement was detected except for memory control A and the foveal integration conditions. In memory control A and foveal integration-latency, the stimulus was presented for a duration approximately equal to the subject's eye movement latency in the visual integration condition. In foveal integration-40, it was presented for 40 msec.   **Each pulse took less than 1 msec to complete. Saccadic events were all parafoveal. There was always a 40 msec interstimulus interval between the end of the stimulus in the first column and the beginning of the stimulus in the last column.   †The second fixation stimulus was presented for 20 msec. Location cited above is relative to the first stimulus and/or the stimulus presented during the saccade.   ††An extra pulse of the first 12 dots was presented to equate the condition with the persistence control condition. However, subsidiary testing indicated no difference in these conditions between (1) an additional pulse of the first 12 dots and (2) no additional pulse.

aspect of the Jonides et al. experiment was that performance was better than that in the original DiLollo experiment, in which no eye movement intervened and the events were all presented foveally, with the first stimulus presented for 160 msec and with an ISI of 40 msec. In our *foveal integration* conditions, the second stimulus was presented for 20 msec (as in the visual integration condition) and the first was presented either for 40 msec (*foveal integration-40*) or for the average latency of the saccade in the visual integration condition (*foveal integration-latency*).

Experimental Design

In Part A of the experiment, the subjects performed in 192 trials in each of the following conditions: visual integration, memory control A, persistence control, and persistence mask 1. In addition, they performed in 64 trials in the two foveal integration conditions. Since we were not completely confident that we had fully controlled for persistence in Part A, Part B was run. In Part B, the subjects performed in 192 trials in each of the persistence mask 5 and memory control B conditions to assess further the effectiveness of the presentation of all 25 dots to mask persistence.

Within each part, conditions were run in blocks of 32 trials and the trial blocks were run in a sequence such that the average

order of the trial blocks in each of the conditions was equated for each part.

RESULTS

Table 2 shows the basic results of the four principal conditions of Part A of the experiment. In addition to scoring judgments correct in terms of absolute accuracy, we also scored judgments in terms of near hits. Thus, the values presented in parentheses in Table 2 correspond to what the accuracy level would be if we scored judgments correct when subjects were off either by one row or by one column in localizing the missing dot. Our rationale for including this more liberal scoring system is that there might have been memory problems in reporting the location of the missing dot. That is, the sequence of events is so rapid that it is entirely possible that subjects occasionally knew (at an unconscious level) or

Table 2
Percent Correct Judgments from Principal Conditions of Part A

| Condition | Subject | | | | |
	K.R.	A.P.	A.I.	J.M.	Mean
Visual Integration	.49(.63)	.47(.59)	.68(.80)	.53(.64)	.54(.67)
Memory Control A	.08(.20)	.08(.18)	.08(.22)	.15(.30)	.10(.22)
Persistence Control	.18(.20)	.35(.50)	.66(.79)	.10(.30)	.32(.49)
Persistence Mask 1	.23(.38)	.28(.38)	.21(.36)	.35(.50)	.27(.41)

Note— Values in parentheses indicate score when lenient scoring criterion was used (see text).

saw the missing dot, but forgot its exact location before they could report it, or they confused its exact location. This less stringent scoring procedure allows us to assess, to some degree, the extent to which memory artifacts are a problem in the study. Of course, this scoring system also increases the chances that pure guessing will result in a correct choice, and it is also more difficult to estimate what a pure guessing score would be. Hence, although we will focus on the data using the more stringent scoring system, the data using the lenient system are presented for comparison.

If we concentrate for the moment on the first two rows of Table 2, it would appear that we have basically replicated the results reported by Jonides et al. Subjects performed well above chance in the integration condition, and the level of performance was comparable to that reported by Jonides et al. On the other hand, performance in the memory control A condition was very poor (10% averaged over subjects). Although chance performance in the task can be thought of as 4%, in reality a closer approximation to chance performance might be about 8%: if subjects respond on the basis of the 12 dots available on the second fixation, they have a 1 in 13 chance of being correct. Using the latter criterion, it is clear that subjects' performance in the memory control A condition was essentially at chance level. The difference between the visual integration condition and the memory control A condition was significant [t(3) = 8.56, p < .01]. Thus, in these two conditions, we replicated the results used by Jonides et al. to argue for visual integration. However, an examination of the remainder of Table 2 reveals that the effect is primarily due to integration of the screen persistence and the second set of 12 dots.

We now turn to a more detailed examination of the data from the various conditions.

Persistence Control Condition

The persistence control condition was designed as a test of the extent to which screen persistence due to phosphor decay was responsible for the effect observed by Jonides et al. As seen in Table 2, when the only available information on the location of the first 12 dots was presented during the saccade, performance reached 32%. It seems unreasonable to assume that the location of the missing dot would have been perceived during the saccade itself: saccadic suppression effects minimize this possibility, and in addition, there would have been considerable retinal smearing of whatever information was registered during the saccade. Subjects, on the average, were correct above chance (1/13) in the persistence control conditions. However, this difference was not reliable over subjects [t(3) = 2.01, p < .10]. There appeared to be considerable variability among the four subjects. J.M. was only slightly above chance,

but the other three subjects were each well above chance (ps < .001) if one assumes binomial variability. Thus, there is strong evidence that screen persistence was a factor in the visual integration condition for three of the four subjects. There was a large difference between average performance in the visual integration and persistence control conditions (54% vs. 32%). This difference was not reliable over subjects [t(3) = 2.389, p < .10], as A.I. showed very little difference; the difference between these two conditions was significant for the other three subjects (p < .02 for A.P. and p < .001 for K.R. and J.M.). However, the differences observed for these three subjects were not necessarily due to true visual integration between fixations, since the amount of persistence may have been less in the persistence control than in the visual integration condition. We will return to this point shortly.

Persistence Mask 1 Condition

As seen in Table 2, when the persistence was masked by a single pulse of 25 dots, performance was lowered from 54% in the visual integration condition to 27%. This difference was significant [t(3) = 4.08, p < .05], again indicating that screen persistence was at least part of the visual integration effect observed. However, since we don't know whether these dots fully masked the screen persistence, we don't know whether to ascribe the significantly better than chance performance [t(3) = 6.110, p < .01] in this condition to interfixation visual integration or to residual persistence effects.[3]

Further Tests for Screen Persistence

In Part A, performance was better in the visual integration condition than in the persistence control condition and performance in the persistence mask condition was much better than chance performance or than that in the memory control condition. However, we were not confident that we had totally controlled for (or masked) persistence. In the former comparison, the dots had been refreshed every 10 msec during presentation of the first 12 dots (about 180 msec) so that screen persistence could have been greater than that produced by one single pulse during the saccade. However, the fact that performance was as good as it was, given only a single brief pulse during the saccade, strongly suggests that screen persistence from the dots presented during the first fixation was a factor in the visual integration condition. In the latter comparison, the single pulse of 25 dots may not have masked the difference in luminance between the first 12 dots and the missing dot because of persistence. For this reason, in some pilot conditions, we had pulsed 24 dots once followed by 25 dots pulsed once (both presented during the saccade) with no stimulus presented during either fixation. In that condition, performance had av-

eraged 15% across the four subjects, indicating that one pulse during the saccade did not fully mask persistence in Part A. We then tried several other combinations and found that one pulse of 24 dots followed by five pulses of 25 dots (all during the saccade) and three pulses of 24 followed by five pulses of 25 yielded performance at or near chance levels (4% and 7%, respectively). Thus, it seemed that pulsing the 25 dots five times during the saccade was sufficient to mask virtually all screen persistence from the first stimulus.

Part B, accordingly, was run to test further for screen persistence. The memory control B condition was employed (rather than the memory control A condition), since there was a saccade in this condition and therefore the five pulses of 25 dots could be presented between fixations to equate visual conditions as closely as possible to that of the persistence mask 5 condition.[4] As can be seen in Table 3, performance in the persistence mask 5 condition was only 7% (3% with the lenient system) better than in the memory control B condition, and the difference was clearly not reliable over subjects. Since we cannot compare directly the screen persistence of 3 rapid pulses occurring right before the 25 dots with about 18 pulses spaced out over about 180 msec before the 25 dots, we cannot say for sure that the 5 pulses of 25 dots removed all effects due to the screen persistence of the first 12 dots in the persistence mask 5 conditions. Part B does suggest, however, that visual integration across saccades, if it does exist, is a small effect.

Subsidiary Conditions of Part A

The foveal integration conditions (see Table 4) essentially replicated DiLollo's data. At short SOAs, performance was quite good, while at long SOAs performance was only 30%. Of primary interest was that performance was substantially worse in the long SOA condition than in the visual integration condition (30% vs. 54%) [$t(3) = 3.21$, $p < .05$]. While there was screen persistence in the visual integration condition, it was equally present in the foveal integration conditions. Furthermore, the first 12 dots were foveal in the latter conditions, which should have enhanced performance. Thus, it appears that there is some sort of forward masking of the persistence by the first 12 dots in the foveal integration conditions that does not obtain when an eye movement is made.

Eye-Movement Latencies

Table 5 presents the average saccadic latency associated with the different conditions in which eye movements occurred, as well as the average latency on those trials in which the subjects were correct. Not surprisingly, there were differences between subjects. Furthermore, conditions in which there was no parafoveal stimulus serving as a target location (the memory control B and the persistence control conditions) yielded considerably longer latencies than those conditions in which there was a parafoveal stimulus. In the memory control B condition, there was a tendency for subjects to look at the first foveal array for a long period of time in an attempt to memorize the display. Such a strategy proved to be ineffective, since, in this condition, performance did not differ within subjects when the latencies were long and when they were short. The final point to be made with respect to the saccadic latencies is that, across all of the conditions of the experiment, there was no indication of a systematic relationship between accuracy and eye-movement latency, which was also reported by Rayner et al. (1978).

GENERAL DISCUSSION

Our primary finding was that the interfixation visual integration effect reported by Jonides et al. (1982) is either small or nonexistent. In the condition in which we were most sure that we had eliminated phosphor persistence of the first 12 dots (the persistence mask 5 condition), performance was only slightly better than that in the memory control conditions and not consistently better for all subjects. Recently, Jonides, Irwin, and Yantis (in press; see also Irwin, Yantis, & Jonides, 1983) have also failed to replicate their earlier finding of a large interfixation visual integration effect while employing two different procedures. First, they used a filter over the CRT that was intended to be particularly effective in reducing the intensity of the long-lasting persistence. In this condition, they failed to obtain evidence for visual integration across fixations. However, the display was fairly dim (Irwin et al., 1983), and the original stimulation may therefore have been ineffective in setting up an adequate visual memory for visual integration across saccades. They also failed to obtain a large visual integration effect when the dots were presented using light-emitting diodes (LEDs), which have decay times shorter than 1 msec.

Table 3
Percent Correct Judgments from Principal Conditions of Part B

Condition	Subject				
	K.R.	A.P.	A.I.	J.M.	Mean
Persistence Mask 5	.18(.27)	.12(.28)	.06(.10)	.16(.32)	.13(.24)
Memory Control B	.05(.24)	.04(.20)	.05(.18)	.08(.20)	.06(.21)

Note—Values in parentheses indicate score when lenient scoring criterion was used (see text).

Table 4
Percent Correct Judgments in the Foveal Integration Conditions

Condition	Subject				Mean
	K.R.	A.P.	A.I.	J.M.	
Foveal Integration-40	.66(.75)	.71(.74)	.70(.75)	.50(.70)	.64(.74)
Foveal Integration-Latency	.28(.56)	.60(.62)	.08(.12)	.23(.40)	.30(.43)
Saccade Latency	120	160	260	185	181

Note—Values in parentheses indicate score when lenient scoring criterion was used. Average saccade latency is presented in milliseconds.

Table 5
Saccade Latencies for Each of the Conditions in Which Eye Movements Were Required

Condition	Subject				Mean
	K.R.	A.P.	A.I.	J.M.	
			Part A		
Visual Integration	136(132)	132(127)	274(267)	189(197)	183(181)
Persistence Control	119(111)	186(215)	343(348)	205(202)	213(219)
Persistence Mask 1	120(134)	130(127)	251(257)	166(162)	167(170)
			Part B		
Persistence Mask 5	110(122)	200(191)	268(259)	145(143)	181(179)
Memory Control B	165(185)	401(396)	467(475)	347(367)	345(356)

Note—Values in parentheses are the latencies for correct trials only.

The LED display was apparently quite bright (Irwin et al., 1983), so the failure to observe visual integration in this condition is even stronger evidence against visual integration. However, there may have been some other aspect of this procedure that worked against visual integration (e.g., the change in color or size of the display). In both experiments, they obtained a small difference (an average of about 3%) between performance in the visual integration and memory control conditions. The important finding, however, was that they were unable to obtain a large visual integration effect when screen persistence was eliminated.

Our experiments, like those reported by Irwin et al., demonstrated a small, insignificant difference between a "visual integration condition" that eliminated screen persistence and a memory control condition. Since a small effect remained, it is possible that there is a small visual integration effect. Even if such a difference were reliable, however, one could only conclude that integration of information across saccades depended on the spatial location of the arrays, but not necessarily that the integration was of literal visual information, as in a visual buffer. All four subjects in our experiment had the clear phenomenal impression that relating information in the visual integration and persistence mask conditions involved far less mental effort than did relating information in the memory control conditions. In the memory control conditions, one had the feeling that one could remember (more or less) either set of 12 dots but not attend to both simultaneously. When

the information was in the same spatial location, on the other hand, there appeared to be no problem with divided attention. Thus, we feel that it is quite reasonable that certain kinds of information may be more easily integrated across fixations when the spatial location is kept at least approximately constant. However, the level of representation of the information to be integrated is not at all clear.

The experiments cited earlier (Rayner et al., 1978, 1980), on the integration of linguistic information, suggested that even though the information that is integrated is relatively abstract, the amount of facilitation may be increased by having the information in the same spatial location. These experiments measured the facilitating effect that parafoveal preview of information about the word had on the time to name a fixated word. Since the facilitation in this paradigm was unaffected by changes in cases of all the letters across fixations, the information integrated was quite abstract (Rayner et al., 1980). However, in another experiment (Rayner et al., 1978), the size of the facilitation was larger in a condition in which an eye movement occurred than in one in which the subject maintained fixation (analogous to memory control A) and the stimuli were in different spatial locations.

Similarly, integration in the present experimental situation also need not be a point-by-point summation in a higher order "retina." Instead, the 12-dot arrays may be coded more abstractly, and the correct spatial location of the missing dot may be estimated by computing where there are large gaps in

each of the two arrays and trying to determine a point or region of overlap of these gaps. These "gaps" need not be computed from actual point-by-point representations in a visual "retinoid" buffer, but can be from more abstract representations (e.g., the verbal coding "big hole in the center"). The originally reported large visual integration effect of Jonides et al. (1982)—50% correct vs. less than 10% in the control condition—was compelling evidence for a visual retinoid buffer, since integrating more abstract codings of the 12-dot arrays would not plausibly lead to that high a level of performance. However, a difference in the range of 5% between the visual integration condition and the memory control does not compel an interpretation in terms of such a "retinoid" buffer.

The stability of the visual world suggests that considerable information of some sort is integrated across saccades. If this is so, then an intriguing question is why performance was so poor in this task when screen persistence was controlled for. The first point to remember is that in an ecologically valid situation a blurry parafoveal image, or some abstraction thereof, is integrated with the information of a sharper foveal image. That contrasts with the present paradigm, in which two complementary, and in some sense contradictory, pieces of information about an object appeared on two fixations. What would make most sense as a representation common to both the blurry and clear image would be a "feature space" in which visual invariants of objects were represented. Since the two sets of 12 dots are clearly not different representations of the same object, integration of information has to go on in spite of the fact that the two images have little in the way of common features. Thus, one might expect integration to be quite poor and slow, as was observed in the present experiments. This argument raises the possibility that the integration effect observed may work only when there is a weak stimulus, due to persistence, that is enhanced by the visual memory of the 12 dots.

The other two psychophysical experiments cited in the introduction seem to be more likely to tap interfixation integration, since they presented identical stimuli on both fixations. Unfortunately, the Wolf et al. studies (1978, 1980), which looked at summation of subthreshold patterns across a saccade, have the same screen persistence problem as the dot matrix experiments. The Ritter (1976) experiment avoided the persistence problem, but is somewhat harder to interpret. In that experiment, a dot was presented both before and after a saccade, and the failure to detect two dots (as opposed to one) was taken as evidence that temporal integration of the two dots had occurred. However, failure to report two dots could also be due to pre- or postsaccadic

suppression of one of the stimuli. The demonstration of integration in this paradigm would be more convincing if it could be shown that the subject had located the single perceived event in time between the two actual physical events.

To summarize, there is clearly some representation of the visual world that we maintain in a short-term memory buffer that captures much of the geometric reality of the visual scene that we see by means of a series of fixations. The present experiments suggest, however, that visual integration in a literal manner, from a series of discrete fixations, is unlikely to be a large contributor to our image of a stable world. Experiments with more complex (and ecologically valid) stimuli are probably needed to discover the kinds of information that are stored in this short-term memory buffer.

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NOTES

1. The subject was usually unaware of the identity of any of the letters in the first string.

2. A saccade of 2-3 deg was measured as taking 25-30 msec, on an average.

3. We were puzzled by the large individual differences among our subjects in the persistence control and persistence mask 1 conditions. One possible explanation was that A.I. was particularly sensitive to small amounts of persistence in the persistence control, but insensitive to *differences* in persistence if both were reasonably bright, as in the persistence mask 1 conditions, whereas J.M. was more sensitive to differences when the persistence was reasonably bright, but less sensitive to small absolute amounts of persistence.

4. Half of the memory control B conditions were run with all 25 dots presented during the saccade in the parafoveal location. Performance on the half of the trials so run did not differ for any of the subjects from the other half of the trials in which 25 dots were not presented during the eye movement.