



Integrating Visual Information from Successive Fixations

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significantly greater after regular elicitation of the relaxation response [$F(1, 10) = 6.80, P < .05$]. This pattern was evident in four of the six crossover subjects. The differences were significant during stress level +15 [$q'(25) = 1.84, P < .05$].

Systolic and diastolic BP increased progressively with graded stresses in both the control and experimental groups (Table 1). During the first session, BP did not differ between groups in any condition. Further, despite the significantly augmented release of plasma NE in the experimental group on session 2, there were no parallel increases in systolic or diastolic BP. Systolic and diastolic BP tended to be lower on session 2 in the experimental group and on session 3 in the crossover group, but the differences were not statistically significant.

Heart rate also increased progressively with graded stresses (Table 1). The two groups were similar on session 1. On session 2, HR levels were not distinguishable from those of session 1 in either group. There were also no changes when sessions 2 and 3 were compared in the crossover group.

In the experimental subjects, after they had regularly elicited the relaxation response for 30 days, the plasma NE response to graded stress was augmented over and above that of the control subjects. Measured concurrently with plasma NE, HR and BP did not change in either group. This result was replicated within this investigation when six of the nine control subjects subsequently elicited the relaxation response for 30 days in a crossover extension.

In accordance with earlier reports (8, 9), our study revealed that plasma NE levels under low-stress conditions (supine posture) did not change after subjects elicited the relaxation response. On the other hand, under high-stress conditions (upright posture and isometric stress), the relaxation response was associated with augmented plasma NE. The cardiovascular responses to postural and isometric stresses are largely mediated by SNS activity. Plasma NE concentrations, the index of SNS activity in our study, increased disproportionately over HR and BP. These data suggest that in subjects eliciting the relaxation response more NE is required to produce the normal compensatory increases in HR and BP.

The elicitation of the relaxation response may reduce adrenergic end-organ responsivity. The mechanism for such a change in this responsivity is not clearly identified (14). These data are consistent

with an earlier study (15) suggesting that subjects eliciting the relaxation response may be less responsive to stress.

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Integrating Visual Information from Successive Fixations

Abstract. *One of the classic problems in perception is how visual information from successive fixations of a scene is integrated to form a coherent view of the scene. The results of this experiment implicate a process that integrates by summing information from successive fixations after spatially reconciling the information from each glimpse. The output of this process is a memory image that preserves the properly reconciled information from successive fixations.*

One of the great puzzles in the psychology of perception is that the visual world appears to be a coherent whole despite our viewing it through a temporally discontinuous series of eye fixations. In a sense, the problem is that our data about a scene consist of individual "snapshots," and yet our perception consists of a single panoramic view (1). We have empirically demonstrated the existence of a briefly lasting memory in which temporally separate glimpses of a display are stored simultaneously and spatially reconciled with one another. With this memory serving as the basis of perceptual experience, the observer literally sees a coherent view of a display that is constructed from the individual glimpses of which it is made. Such memory could subserve the translation of information originally coded by retinal coordinates into information coded by spatial coordinates, the way we ultimately experience it.

To empirically establish this phenomenon of information integration across fixations, we used an experimental task modeled after one used by DiLollo (2). The task required subjects to localize a missing dot in a 5 by 5 dot 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; after a brief interval, the second frame was displayed. In order for a subject to determine the location of the missing dot, his visual system had to integrate the two separate frames into a single representation of the matrix. We modified DiLollo's version of this task by manipulating the presentation of the two frames of dots. Subjects viewed the first frame while they fixated one location on the screen, and they saw the second frame (in the same spatial location as the first) only after they had shifted their gaze to another screen location (Fig. 1). With this procedure, the two frames of dots were presented in the same spatial area, but subjects viewed them during different fixations. Hence, the images of the two frames fell on different retinal areas. With this modification, successful integration of the frames required that subjects make use of the spatial overlap of the frames to overcome their lack of retinal overlap.

To assess the quality of performance in this condition, we included a control condition in which subjects did not execute a saccade; the frames were presented to the same retinal areas as in the

saccade condition, but they did not overlap spatially as they did in the saccade condition (Fig. 1).

The stimuli were presented on the face of a point-plotting graphics device with a fast-decaying P-4 phosphor. Eye position was monitored by a scleral reflectance device whose output was analyzed by computer (3). Three subjects participated in each of two conditions.

In the saccade condition, the first frame of dots appeared to the right of a fixation cross in the center of the screen, with the dots centered 4° from fixation, subtending 3° of visual angle. This frame remained in view for a fixed duration chosen individually for each subject: subject 1, 127 msec; subject 2, 147 msec; and subject 3, 187 msec. These times represent the mean latencies of saccadic movements as measured separately for each subject in a preliminary psychophysical procedure.

Subjects were instructed to shift their gaze from the fixation point to the location of the first frame when it appeared. The duration of frame 1 was set at the mean saccade latency of each subject so that, on the average, just as subjects initiated their saccades in this condition, frame 1 would disappear from view. After the first frame was extinguished, the screen was blank for 37 msec. This blank interval corresponds to the mean duration of the subjects' saccades. On the average, while subjects shifted gaze from the fixation mark to the location of frame 1, the screen was dark. The second frame of dots then appeared for 17 msec in the same area as the first frame, such that if the two frames were superimposed, only one dot from the 5 by 5 matrix would seem to be missing. After the second frame was extinguished, subjects indicated which of the 25 dots had not been presented by typing row and column coordinates on a keyboard.

The control condition closely mimicked the saccade condition with respect to the retinal locations of the two portions of the display, but required no eye movement. In the control condition, the two frames of dots did not spatially superimpose. That is, the two frames were presented in different spatial locations from one another, and subjects gazed directly only at the location of the second frame, not the first. This rendered the retinal projections, but not the spatial projections, nearly identical in the two conditions.

The trials of the saccade condition that are of main interest are those in which frame 1 was viewed only while subjects were gazing at the fixation location and frame 2 only after subjects had shifted

their gaze to the location of the dots. Only these trials are included in the analyses reported (4).

Accuracy in the saccade condition was substantially better than that in the control condition, by nearly an order of magnitude in percentage points (the difference between conditions averaged 52.5 percent, with a 95 percent confidence interval halfwidth of 11.6 percent). In addition, we noted subjects' verbal reports about their phenomenological experience in the saccade condition. They all reported that on some trials, after they had shifted their gaze and the

second frame had been presented, they "saw" a single image of 24 simultaneously perceived dots with an obvious gap in the image corresponding to the missing dot (5). No such reports were provided, even after prompting, for the control condition. This introspection invites the conclusion that the process operating to integrate images of the two frames makes use of information that is stored in a form similar to the actual displays.

Another feature of performance is revealed by error patterns (Table 1), which suggest that the process of integrating

Table 1. Accuracy during saccade and control conditions. Frame onset asynchrony is the time elapsing from the onset of frame 1 to that of frame 2.

Subject	Frame onset asynchrony (msec)	Trials (No.)	Accuracy (%)	Errors (%)	
				Frame 1	Frame 2
<i>Saccade condition</i>					
1	164	200	53.0	72.3	27.7
2	184	204	60.8	22.5	77.5
3	224	205	62.0	21.8	78.2
<i>Control condition</i>					
1	164	214	8.4	83.7	16.3
2	184	224	5.4	84.4	15.6
3	224	194	4.6	84.3	15.7

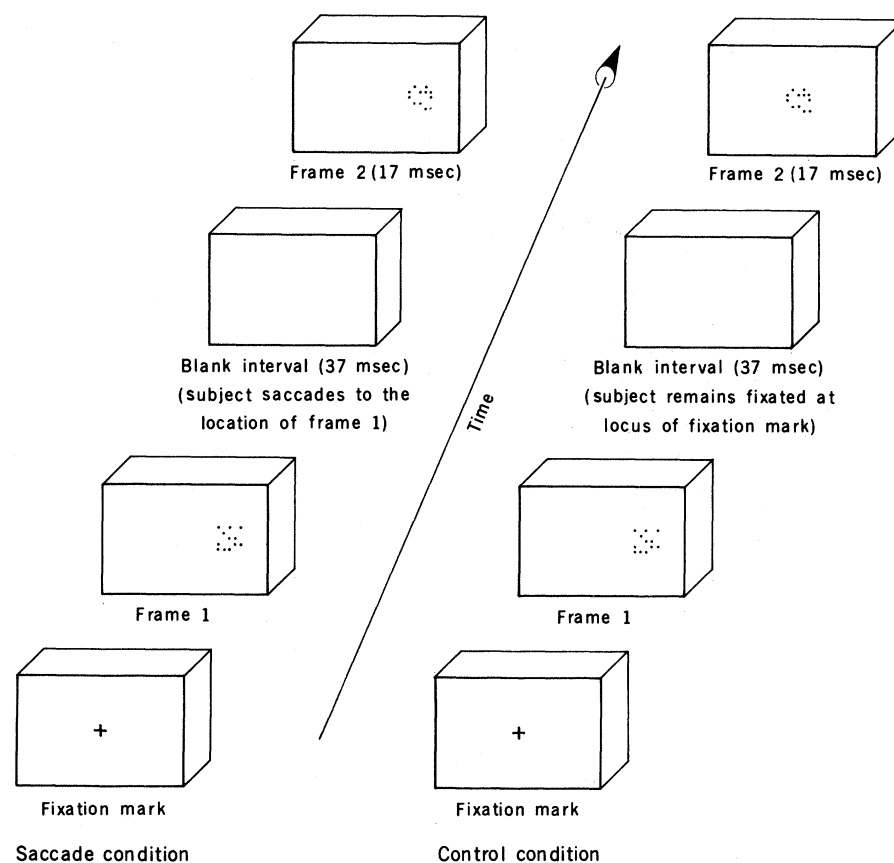


Fig. 1. The sequence of events for the saccade and control conditions. The rectangles indicate the stimulus events that occurred over time. The eye positions that subjects were required to maintain in each condition are also shown. When the two frames are combined in this illustration, the missing dot is in row 3, column 2.

images of the two frames renders information in the first frame more resistant to forgetting than information in the second: Most errors in the control condition were reports of a location that actually contained a dot in frame 1, not frame 2; in contrast, the reverse was true for two subjects in the saccade condition.

Thus, when two packets of information were presented at the same spatial location, but viewed during two different fixations so that their retinal locations were different, subjects saw the two packets as one image at the same spatial location. But when the spatial locations of the packets differed, even though the retinal coordinates were matched to the condition that produced integration, subjects saw two spatially separated images that they could not easily integrate. In both cases, perceptual experience reflects environmental events.

We hypothesize that the integration of information indicated by the saccade condition requires the use of a special memory, previously named an integrative visual buffer (6). Our experiment implies that packets of information with the same spatial coordinates, but different retinal coordinates, are properly aligned spatially in the buffer (7). This fused and spatially correct image is then available for further information processing (8).

At least two identifiably different memories may be involved early in the stream of visual information processing. One piece of evidence supporting this conclusion comes from a comparison of the time course of the integration phenomenon when the eyes move with the time course when no eye movements are required (2). Across subjects, accuracy increased as frame onset asynchrony increased from 164 to 184 to 224 msec (Table 1). This effect may obtain within a single subject as well: Subject 3 was rerun in the saccade condition with a signal to initiate his saccade before frame 1 onset, and with frame 1 durations of 27, 87, 127, and 167 msec (and hence, frame onset asynchronies of 64, 124, 164, and 204 msec). His accuracy was 41.9, 59.5, 53.5, and 63.4 percent, respectively. This result suggests that there is either an increase or no change in performance with frame onset asynchrony within the range investigated. In either case, it stands in contrast to that reported for integration within a single fixation (2), where accuracy decreases with increasing frame onset asynchrony within a similar range of values. This comparison suggests that different mechanisms underlie integration in the two contexts.

One intriguing possibility to account for these different effects is that early in the visual system, there is a storage site in which information is coded retinotopically, and in which this information is subject to integration and erasure effects by new entries that arrive within some time window. Later in the system, there may be another storage site that codes information by environmental coordinates, one that has a different set of time variables governing integration and erasure. Our results, along with the results of others, begin to lay the groundwork for investigating this second stage of information storage (9). This, in turn, offers a new opportunity to understand one of the most fundamental and intriguing of perceptual phenomena, the experience of a continuous visual world despite temporally discontinuous input.

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1. The problem is exacerbated by saccadic suppression, a phenomenon in which the quality of visual input during saccades is substantially reduced [E. Matin, *Psychol. Bull.* **81**, 899 (1974)].
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3. The eye monitoring equipment was sensitive to saccades of 0.5° and to deviations from fixation of even lesser extent.
4. Since the duration of frame 1 was set at the mean

of subjects' saccade latency, and since there is variability around this mean in actual latencies, there were many trials in which subjects shifted their fixation either before frame 1 was extinguished or after frame 2 had been presented. These trials were excluded from analysis. The remaining trials that met the requirement stated in the text represent 44, 66, and 51 percent of the total for the three subjects, respectively.

5. Adequate precautions were taken to ensure that this persistence could not have been a function of the graphics display device itself.
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7. Our experiments do not implicate any particular mechanism as the critical component in spatial reconciliation. It may be, for example, that extraretinal signals play an important role [H. von Helmholtz, *A Treatise on Physiological Optics*, J. P. C. Southall, Transl. (Dover, New York, 1963) (originally publ. 1909-1911); A. A. Skavenski, in *Eye Movements and Psychological Process*, R. A. Monty and J. W. Senders, Eds. (Erlbaum, Hillsdale, N.J., 1976)], or perhaps visual information from the retinal images themselves is sufficient [J. J. Gibson, *The Ecological Approach to Visual Perception* (Houghton Mifflin, Boston, 1979)].
8. Using time variables similar to ours, Matin has shown that people are poor at spatially reconciling the contents of two fixations to make relative position judgments [L. Matin, in *Handbook of Sensory Physiology*, vol. 7, part 4, *Visual Psychophysics*, D. Jameson and L. M. Hurvich, Eds. (Springer-Verlag, Berlin, West Germany, 1972)]. Using a different task, however, we have demonstrated that subjects can integrate information from two fixations to create a combined representation that has emergent perceptual properties (that is, a gap where no dot was presented).
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How Do We Avoid Confounding the Direction We Are Looking and the Direction We Are Moving?

Abstract. *Contrary to a previous assumption, the center of the expanding pattern of visual flow is not generally useful as an aid in judging the direction of self motion since its direction depends on the direction of gaze. For some visual environments, however, the point of maximum rate of change of magnification in the retinal image coincides with the direction of self motion, independently of the direction of gaze. This visual indicator could be used to judge the direction of self motion.*

How does an airplane pilot or an automobile driver judge his direction of motion when vision is the only guide? One strategy would be to assume that the aircraft or car always travels at a fixed angle relative to the way it is pointing, but a pilot or driver using this strategy should expect directional judgments to fail when the aircraft yaws or when the car spins on ice. Other possible strategies have been suggested. Gibson (1) underlined the geometrical fact that, while an observer is moving forward, the retinal image of the outside world is necessarily undergoing continuous geo-

metrical transformation. Figure 1, however, illustrates that, for a given direction of self motion, the retinal image flow pattern is strongly affected by the direction of gaze. Although previously noted (2), this point often seems to have been ignored in studies of visually guided locomotion (3). One consequence is that Gibson's much-quoted statement that the center or focus of the expanding flow pattern during forward motion corresponds to the observer's destination (1) is not generally correct. For the specific case illustrated in Fig. 1, Gibson's statement is not true if the observer looks at