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# The effect of expectation and available processing time on recognition of sequences of naturalistic scenes

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In four experiments, we examined the effect of the amount of available processing time and subjects' expectations about available processing time on recognition memory performance. Results indicated that both expectation and actual available processing time are important in determining memory performance.

The effect of the amount of available processing time on memory performance is of interest because one can make inferences about cognitive processes on the basis of such effects. Intuitively, it would seem that increasing the amount of time available for processing would improve memory performance. In fact, however, the issue is more complex. Although both stimulus duration (Potter & Levy, 1969; Shaffer & Shiffrin, 1972) and interstimulus interval (ISI) (Intraub, 1979, 1980; Tversky & Sherman, 1975; Weaver, 1974) affect performance, other factors mitigate the size of the effects.

One factor that influences performance is the subjects themselves. Subjects have considerable control over the encoding process. In these experiments, we examined the effects of available processing time and of subjects' expectations about timing on memory performance for sequences of visual stimuli.

Our stimuli were complex naturalistic pictures arranged in categorized sequences, for example, a sequence of mountain scenes. Categorized sequences were used because they encourage the subject to distinguish one stimulus from another on the basis of visual characteristics rather than by using verbal identifiers, they require more time to process than simpler stimuli, and they are more similar to the stimuli we encounter in our visual world.

## EXPERIMENT 1a
## 400-msec ISI

In Experiments 1a and 1b, we held ISI and duration constant; thus, subjects were knowledgeable about the timing of upcoming events. Available processing time varied between experiments; ISI was 400 msec in Experiment 1a and 1,200 msec in Experiment 1b. We examined the effect of available processing time by comparing the shape of the serial-position curves. Experiments 1a and 1b are reported separately as they were executed separately; however, a final discussion section compares their results.

### Method

Because the methodology for the four experiments is quite similar, the methodology for Experiment 1a is described in detail and only methodological changes are subsequently reported.

**Subjects.** Sixty-seven University of Washington undergraduates participated in Experiment 1a for course credit. They were run in 12 groups of 5-8 subjects per group.

**Materials.** The stimuli were naturalistic photographs prepared as 35-mm color slides. There were eight categories: bodies of water, cars, fields and valleys, boats, mountains, houses, seashores, and roads. Twenty-four slides were chosen from each category. Half were designated as targets, half as distractors. A dim adapting field was present throughout all experiments. The luminance of the slides ranged from 5.0 to 116.1 cd/m$^2$. The luminance of the projector when on with no slide was 96.6 cd/m$^2$. The luminance of the adapting field was 0.1 cd/m$^2$. All readings were taken at the center of the screen. The luminance of the fixation point was 1.1 cd/m$^2$.

**Apparatus.** Stimuli were displayed via one Kodak random-access projector and four Kodak standard projectors. The random-access projector was used to present the distractor slides and a dim fixation point that began each trial. Timing was controlled by Gerbrands tachistoscopic shutters with rise and fall times of approximately 1 msec. Stimuli subtended a visual angle that ranged from 18° to 28° horizontal and from 13° to 20° vertical, depending on where the subject sat. Slides were projected onto a white screen set against a black wall. All display equipment was enclosed in a soundproof box. Responses were collected on 16-key response boxes. Display and response-collection equipment was controlled by an IBM-AT-compatible computer system.

**Design and Procedure.** A *trial* consisted of a sequence of 12 sequentially displayed stimuli. The stimuli were shown consecutively over projectors; thus the 1st slide in a trial was projected from one projector, the 2nd slide from the next projector, and so on. To achieve counterbalancing of slides over serial position, the starting projector and the starting slide were systematically manipulated over groups. Complete counterbalancing of slides over the 12 serial positions required 12 groups of subjects.

The subjects were informed about the sequence of events that would occur and were instructed to try to remember all the pictures that they saw. Each trial began with the experimenter informing the subjects of the category for that trial. A 500-msec, 850-Hz tone signaled the start of the sequence. The tone was followed by a 50-msec fixation point and a 500-msec pause. Each of the 12 stimuli in a trial was then shown

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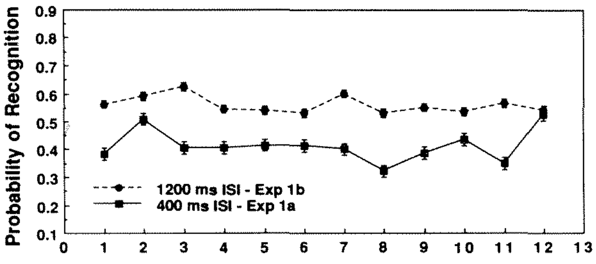

**Figure 1. Experiment 1: Constant ISIs.**

for 100 msec and followed by a 400-msec ISI. The total study time for a trial consisted of 500 msec of tone time, 550 msec of fixation time, and 6,000 msec of display and ISI time, for a total of 7,050 msec.

Immediately following each trial, a recognition test was given that was composed of an equal number of targets and distractors. The target/distractor order of test was random but constant for all subjects in an experiment. For each test stimulus, the subjects were asked to respond "yes" or "no" depending on whether they thought they had seen the picture in the preceding study phase. The subjects responded by pressing one of two specified keys on their response boxes after they heard a 100-msec beep that occurred 500 msec following the test picture's onset. Each test picture remained on the screen until all subjects had responded.

The experimental session was composed of eight study-test sequences. The first trial was considered as practice, and its results were excluded from all analyses.

### Results

All results (hit rates) reported in this and subsequent experiments were corrected for the false-alarm rates.[1] Results of Experiment 1a are presented in Figure 1, along with those from Experiment 1b. A planned comparison indicated that performance on the last position was significantly different from the mean of the other 11 positions $[F(1,726) = 7.74]$. (Unless otherwise indicated, reported results are significant at the .01 level.) Thus, for the 400-msec ISI sequences, there was a recency effect.

Mean recognition performance for Experiment 1a was .41. The false-alarm rate was .28, and the standard error of the mean was .022.[2] The error bars are appropriate for assessing the pattern of means over serial positions.

## EXPERIMENT 1b
## 1,200-msec ISI

In Experiment 1b, the ISI was increased from 400 to 1,200 msec. The design of the experiment was otherwise the same as in Experiment 1a.

### Method

Seventy-seven undergraduates were run in 12 groups of 5-8 subjects per group. ISI was 1,200 msec.

### Results

Mean corrected recognition performance was .56. The false-alarm rate was .24, and the standard error of the mean was .013. Inspection of Figure 1 reveals no increment for the last serial position; a planned comparison of the last serial position against the mean of the other 11 serial positions confirmed this $[F(1,836) = 2.08, p > .10]$.

### Discussion: Experiments 1a and 1b

There are differences in the shape of the serial-position curves. With a 400-msec ISI in Experiment 1a, there was a recency effect; with a 1,200-msec ISI in Experiment 1b, there was no recency effect. Overall accuracy was significantly lower when the amount of available processing time was less $[t(146) = 2.78]$. In the 400-msec-ISI experiment, each stimulus after the first cuts off processing of its predecessors and accuracy is thus reduced. In contrast, the 1,200-msec ISI is apparently all the postoffset processing time the subject needs.

The results of Experiments 1a and other experiments with relatively briefer ISIs (Intraub & Nicklos, 1981) or stimulus durations (Hines, 1975; Potter & Levy, 1969) suggest that, when available processing time is brief, subjects will utilize more available processing time after the last item than has been available for other sequence items and there will be a recency effect. In contrast, in situations where the available processing time is relatively long, as in Experiment 1b, the ISI itself provides sufficient time; there is therefore no differential processing between the last item and other sequence items. Indeed, performance for the last position was about the same for the two experiments: .53 for Experiment 1a and .54 for Experiment 1b $[t(146) < 1.0]$.

The one-item recency effect in the 400-msec condition also suggests that, with limited processing time, the subjects are switching attention to each item serially. If multiple items were processed together, the subjects would use available time following the last item to continue processing of the two or three previous items for which they had insufficient processing time, and the result would be a multiple-item recency effect, not the observed single-item recency effect.

## EXPERIMENT 2
## Varied ISIs

In Experiment 2, we examined the effect of varying intratrial ISIs on recognition accuracy and on the shape of the serial-position curve.

### Method

In Experiment 2, 208 undergraduates were run in 36 groups of 5-8 subjects per group.

Three ISIs of 400, 800, and 1,200 msec were contained in a trial. The subjects were informed that the interval between the pictures would vary. There were three presentation orders of ISI, and ISI order was counterbalanced across trials and groups. Slide, serial position, and ISI were completely counterbalanced. Each stimulus was seen in all serial positions and at all three ISIs.

### Results and Discussion

Figure 2 shows memory performance for serial positions at a given ISI. For example, in the 400-msec-ISI condition, the second point represents performance for all trials for which the second serial position had a 400-msec ISI. Mean corrected hit rates for the three ISIs were .44, .50, and .55 for the 400-, 800-, and 1,200-msec ISIs, respectively, which were significantly different $[F(2,414) = 71.46]$, as Figure 2 reflects. The false-alarm rate was .27, and the standard error of the mean was .015.

In this experiment, the subjects were informed that the interval between the pictures would vary. Results suggest that they were able to use this information successfully; the corrected hit rates are comparable to those obtained in the constant-ISI experiments ($ts < 1.0$).

A planned comparison for the 400-msec condition indicated that performance on the last position was signifi-

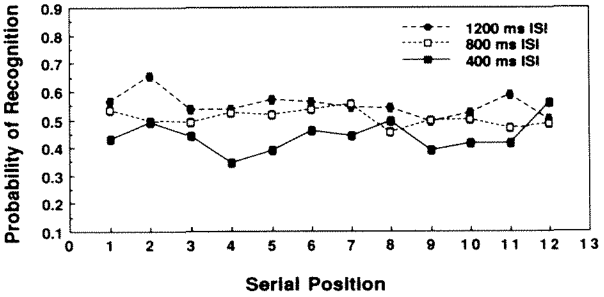

**Figure 2. Experiment 2: Varied ISIs.**

cantly better than the mean of the other 11 positions [$F(1,2277) = 21.08$]. The result replicates Experiment 1a, in which the ISI was 400 msec. For the 800-msec-ISI positions, the planned comparison of the last position against the mean of the other 11 was not significant [$F(1,2277) < 1.0$]; for the 1,200-msec-ISI positions, the last position was significantly lower than the mean of the other 11 positions [$F(1,2277) = 13.69$].

In Experiments 1 and 2, the subjects could anticipate the timing of events: either the presentation pattern was constant, or they expected the pattern to vary. This knowledge may have permitted them to better utilize available processing time. In contrast, in the Shaffer and Shiffrin (1972) experiments, which showed no effect of ISI, and in the Proctor (1983) replication, subjects were uninformed about timing variability. Results of Experiments 1 and 2 imply that the ability to anticipate subsequent events may be an important variable in determining subjects' later memory performance. We investigated this variable further in Experiment 3.

## EXPERIMENT 3
## Attentional Instructions

There is other evidence that subjects can exert considerable control over the attention-switching process. For example, Intraub (1984) instructed subjects to focus their attention on brief or long pictures in sequences of alternating brief- and long-duration pictures. She found that memory performance was better for the focused-upon pictures. Similarly, Graefe and Watkins (1980) showed better memory performance for the cued than the uncued picture in a pair.

In Intraub's (1984) experiment, there was a performance decrement for long-duration pictures when subjects were instructed to attend to brief items. In contrast, in the Graefe and Watkins (1980) experiment, cuing a specific picture did not affect recognition performance for the other member of the pair relative to baseline performance.

In Experiment 3, the subjects were instructed to remember all the pictures but to pay particular attention to the picture at one position on each trial, the *target serial position*. The question was how this instruction would affect the subjects' memory performance for the item at the target position and for the items preceding and following it.

### Method

**Subjects**. Seventy-one University of Washington undergraduates were run in 12 groups of 5-8 subjects per group.

**Design and Procedure**. The ISI was 1,200 msec, as in Experiment 1b. The target serial position was 5, 6, or 7. Across the eight trials, there were three orders of target serial position; each order was used for four groups of subjects. Slide and serial position were counterbalanced as in Experiments 1a and 1b; one third of the slides appeared at each of the three target serial positions when it was a target serial position.

The subjects were instructed to try to remember all the pictures that they saw but to pay special attention to the picture at one serial position, 5, 6, or 7. The subjects were also told to count the pictures to themselves to keep track of the picture positions in the trial and that there would be a reminder beep before the special picture. Each trial began with the experimenter informing the subjects of the category and the target position for that trial. To alert the subjects, a 100-msec, 500-Hz tone occurred prior to the onset of the target picture.

### Results and Discussion

As Figure 3 shows, the subjects were able to follow instructions to pay special attention to one serial position: their memory performance was significantly better for the targeted serial positions, as is reflected in the curve (target position 5, 6, or 7) × serial position interaction [$F(22,1540) = 6.92$]. A planned comparison of the three target serial positions against the other 33 positions in the three curves was significant [$F(1,1540) = 108.37$] and accounted for 51% of the variance attributable to serial position, curve, and the serial position × curve interaction.

In Experiment 1b, the mean recognition probability was .56, compared with .46 in Experiment 3. The reduction of approximately .10 was not significant, however [$t(146) < 1.0$]. A Scheffé test for multiple comparisons (Edwards, 1972) showed that recognition performance for the last five serial positions was significantly lower than it was for the first four serial positions [$F'(8,560) = 20.38$, $p < .05$]. Thus, memory performance for the items succeeding the target is most affected.

It seems that there is a cost for subjects to pay special attention to one serial position. This is in accord with Intraub's (1984) result but conflicts with that shown by Graefe and Watkins (1980). What is the difference? In Graefe and Watkins's experiment, the cue is presented after each pair, so the attentional instructions change on an item-by-item basis. In Intraub's experiment, the instruction is before the sequence only. Although there is a tone reminder in Experiment 3, the subjects are instructed to count to themselves to keep track of their po-

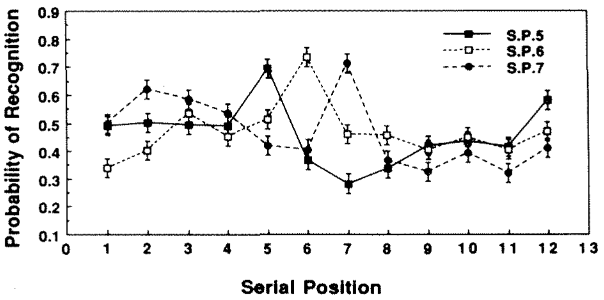

**Figure 3. Experiment 3: Special attention to one item.**

sitions relative to the target. Thus, in both Experiment 3 and Intraub's experiment, the subjects remember the instructions as they proceed through the sequence.

These results suggest again that subjects can control the processing of items in a sequence. When the target event has occurred, to facilitate memory, subjects continue to encode it while processing succeeding items; this leads to a decrement in memory performance for the items following the target. The performance decrement for later items suggests that both the target and items succeeding it are being processed together.

The means for the three curves were .46, .47, and .47 with targeted positions 5, 6, and 7, respectively [$F(2,140) < 1.0$]. The false-alarm rate was .22, and the standard error of the mean was .03. Although all three curves show an increment at the last serial position, a planned comparison with the data collapsed over all three curves was not significant [$F(1,770) < 1.0$], thus, there is not a significant recency effect.

## DISCUSSION

Our results indicate that subjects use information about the timing of upcoming events to develop an encoding pattern. If they know exactly when the next item will occur, as in the constant-ISIs experiments, or if they know that timing will be variable, as in the varied-ISIs experiment, they switch their attention to each succeeding item in the sequence. Such serial processing does not serve them well in other circumstances. When the sequence contains an expected target event, subjects do not process items serially. Instead, more than one item is processed at a time. Thus, subjects choose and use the most efficient processing mode given the knowledge that they have about the timing of upcoming events.

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### NOTES

1. The equation for the corrected probability of recognition is:

$$p(\mathrm{Rn}) = [p(\mathrm{H})-p(\mathrm{FA})]/[1-p(\mathrm{FA})],$$

where $p(\mathrm{Rn})$ is the corrected probability of recognition, $p(\mathrm{H})$ is the probability of a hit, and $p(\mathrm{FA})$ is the false-alarm probability.

2. To compute the est$\sigma_M$ in this within-subject design, we divided the square root of the MSI (subject × serial position) by the square root of $n$ (Loftus & Loftus, 1982).

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