VISUAL VERY-SHORT-TERM MEMORY IS NONASSOCIATIVE[1]

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An array of alternating black digits and letters on a white background was presented for 50 msec. at an illumination of 20 ftl., followed by a dark delay varying from 200 msec. to 2 sec., followed by a black test character on a gray background (500 msec. at .11 ftl.), followed by 4 sec. in which Ss recalled the character appearing to the right of the position of the test character. A visual very-short-term memory trace was obtained for six out of eight Ss, decaying with a time constant of about 2 sec. All Ss had a substantial "nondecaying" tachistoscopic memory component. Presenting as a test character the character which had actually appeared in that position in the preceding array did not enhance recall at any delay for any S by comparison to presenting a dummy character in that position. Thus, tachistoscopic memory is nonassociative. Memory for position is by an ordered, two-dimensional array of locations, not by associations between character representatives.

Retention functions for tachistoscopic memory of an array of characters appear to have two components, a rapdily decaying component, visual very-short-term memory, and a component that can be considered as not decaying at all under the conditions of these experiments—asymptotic memory (see, e.g., Averbach & Sperling, 1961).

In analyzing any type of memory, one of the most fundamental questions to answer regarding the basic structure of that memory is whether it is associative or nonassociative. In an associative (content addressable) memory, each event has a unique internal representative, and the internal representatives have different degrees of association to each other depending upon how frequently and recently they have been contiguously activated.

In a nonassociative memory, there is an ordered set of locations (cells, registers, boxes, etc.) into each of which the internal representative of any event can be coded. Sequences of events are stored in order in this ordered set of locations. A tape recorder is a good example of a nonassociative memory. From a hardware viewpoint, virtually all computer memories are also nonassociative, although with suitable programming, an associative memory can be simulated.

Verbal short-term memory (delays up to 20 sec.) and verbal longer term memory (delays greater than 20 sec.) appear to be associative (see Wickelgren, 1965a, 1965b, in press).

The primary purpose of the present study was to determine the associative or nonassociative nature of both visual very-short-term memory and tachistoscopic asymptotic memory. The basic method is to determine whether cueing recall of the character in a given position is aided by presentation at the time of recall of the correct character in the adjacent position (to the left of the position to be reported on). If associations are formed in tachistoscopic memory between the internal representatives of adjacent characters, then presenting the correct adjacent character should enhance recall. If no such associations are formed in tachistoscopic memory, then there should be no difference between recall with and without the correct adjacent character given at the time of recall.

The design of the present experiment controlled for two potentially confounding factors. First, to equalize any masking effects

of the cue field, cueing of a position to be reported on was by means of presenting a character in the adjacent position to the left in all conditions. Half of the time this was the correct character for that position, and half of the time it was a character which Ss knew never appeared in any array.

Second, if the character in an adjacent position is a potent competitor to the correct character in recall, then cueing by giving the correct adjacent character could aid recall for reasons that have nothing to do with there being associations between adjacent items. Namely, such cueing would aid recall by removing a potent competitor. To eliminate this potential artifact, arrays consisted of two rows, each row containing alternating digits and letters. Thus, Ss always knew that when they were given a digit cue, they were to report the letter in the adjacent position to the right, and when they were given a letter cue, they were to report the digit in the adjacent position to the right. This design eliminates competition in recall from adjacent characters in a row of the array.

Since there appear to be two component memory traces mediating tachistoscopic memory, visual very-short-term memory and tachistoscopic asymptotic memory, it is possible that one of these memories might be associative and the other nonassociative. Assume that asymptotic memory is formed immediately after presentation. If asymptotic memory were associative and very-short-term memory were nonassociative, one would expect to find a constant difference between the correct and incorrect cue conditions at all delays. If very-short-term memory were associative and asymptotic memory were nonassociative, one would expect to find a difference at short delays which disappeared at longer delays. If both very-short-term memory and asymptotic memory were associative, one would expect to find a large difference at short delays which decreased somewhat at longer delays, but was still significant at even the longest delay. Finally, if both very-short-term memory and asymptotic memory were nonassociative, one would expect to find no difference between the correct and incorrect cue conditions at any delay.

A subsidiary purpose of the present study was to replicate, with a larger number of Ss, the relatively slowly decaying visual very-short-term memory traces (time constant in the vicinity of 2 sec.) obtained by Averbach and Sperling (1961) for the dark prefield and postfield conditions. Subsequent studies using dark prefields and postfields by Eriksen and Steffy (1964) and Keele and Chase (1967) obtained, respectively, no very-short-term memory component at all and a rather rapidly decaying very-short-term memory component with a time constant in the vicinity of 200 msec.

Finally, the present study explored the use of a recognition test of tachistoscopic memory in which a test character was superimposed on top of the tested position in the array. One expectation was that a superimposed recognition test character would largely destroy the tachistoscopic memory trace for the tested position. However, it seemed possible that use of a dimly illuminated, low-contrast test character would avoid much of this interference effect.

METHOD

Recall Experiment

Procedure.—On each trial, S heard a "ready" signal, followed in 1 sec. by an array of black letters and digits on a white background which was presented for 50 msec. to the right eye at an illumination of 20 ftl., followed by a dark delay which varied in duration from 200 msec. to 2 sec., followed by a black test character on a gray background which was presented for 500 msec. to the right eye at an illumination of .11 ftl., followed by a 4-sec. period in which S attempted to recall the character which appeared to the immediate right of the test character. This was followed by an intertrial interval of about 15 sec. in which E recorded the response and prepared the stimuli and delay duration for the next trial. During the intertrial interval until presentation of the array, there was a dim red fixation dot in the center of the binocular field which was in the same position as the right-eye field to which the arrays and cues were presented. To reduce any masking effects of the cue stimulus, the present study employed cue characters which had much lower contrast with the background and much lower illumination than the characters in the original stimulus arrays. On 2% of the trials, Ss claimed that they had not seen the array, and these trials were discarded.

Materials.—Arrays consisted of two rows of six characters each, alternating digit, letter, digit, letter, digit, letter, from left to right as viewed by *S*. All 12 characters in an array were different. The six letters in an array were chosen randomly without replacement from the following set of 19 consonants: B, C, D, F, G, H, J, K, L, M, N, P, R, S, T, V, W, X, and Z. The six digits in an array were chosen randomly from the set: 1, 2, 3, 4, 5, 6, 7, and 9. Black Lettraset letters and digits (No. 73-24) with a reflectance of about 3% and white 3 × 5 in. cards with a reflectance of about 90% were used to construct the arrays for presentation in a 5-field tachistoscope described in an earlier paper (Wickelgren, 1967). The gray test card had a reflectance of 10%. The characters had an average width of .8° and an average height of 1.4°. The space between the center of one character and the center of the adjacent character in a row was 1.9°, and the space between the centers of characters in the top and bottom rows was 3.6°. Thus, the array consisted of relatively large characters which were widely spaced, occupying a total visual field 10.3° wide by 5° high.

Design.—There were six different delays: 200, 300, 500, and 700 msec., and 1 and 2 sec. There were two different cueing conditions: correct vs. incorrect adjacent letter. When the cue (probe) letter was incorrect for its position, *S*s always knew that it was incorrect because in this case it was always the letter "A" or the digit "8," which *S*s knew could never appear in an array. The 6 × 2 = 12 conditions were randomly ordered in blocks of 12 trials. There were 18 blocks in a set and three sets. Thus, there were 18 × 3 = 54 occurrences of a condition for each *S*. The three sets used the same 18 × 12 = 216 different arrays, but with a different cue letter and a different order of conditions. The 18 occurrences of a condition in a set included exactly 2 occurrences each of tests of positions 2, 3, 4, and 5 in each row and exactly 1 occurrence each of a test of Position 6 in each row. Six *S*s finished all three sets; two *S*s had to leave town after completing about two sets. It took about 1½ hr. to complete a set, allowing for a 5-min. break halfway through the session and for five practice trials at the beginning of the session and one after the break.

Subjects.—The *S*s were 8 Massachusetts Institute of Technology undergraduates, who were paid for their services. The 8 *S*s were selected from a larger set of 17 people on the basis of high performance on various pretest versions of the present experiment. Many of the rejected *S*s would presumably show little or no visual very-short-term memory under the conditions of the present experiment. Until visual very-short-term memory can be demonstrated in all *S*s, the generality of the present results must obviously be limited to those *S*s who show substantial visual very-short-term memory.

Recognition Experiment

The materials were the same as in the recall experiment. The *S*s were seven of the eight who participated in the recall experiment. The procedure was identical to that in the recall experiment, except that *S*s judged the cue character for its occurrence or nonoccurrence in the previous array. In addition to the "yes–no" recognition-memory judgment, *S*s also stated their confidence in the decision on a scale from 1 (least) to 4 (most). The cue character could be correct or incorrect for its position in the array. If it was incorrect, naturally, it was a character that could have appeared in the array at the position (that is, it was not a character such as "A" or "8" in the recall experiment, which could never appear in an array). Note that an incorrect character could be a character that had appeared in another position in the array. Incorrect characters were chosen randomly with equal probability. Only one delay duration was used, 200 msec. The same positions in the array were tested in the recognition experiment with the same relative frequency as in the recall experiment. The two conditions were randomly ordered in blocks of 36 trials, with six blocks (216 trials) in the one set used. As in the recall experiment, there were five practice trials at the beginning of the set and one after a 5-min. break halfway through the set. The recognition experiment was always run between Sets 2 and 3 of the recall experiment.

RESULTS AND DISCUSSION

Recall Experiment

Chi-square tests were performed comparing the frequency of correct recall in correct and incorrect cue conditions for each of the six delay conditions for each of the eight *S*s. Of these 48 comparisons, 23 favored the correct cue condition and 25 favored the incorrect cue condition. Only 2 of the 48 comparisons were significant at the .05 level, a frequency well within chance limits. Lumping across delay conditions or *S*s failed to yield any significant differences by either a Wilcoxon signed-ranks test or a chi-square test. In short, there is no significant difference between cueing recall of a position by the correct adjacent letter and cueing recall by an incorrect adjacent letter. This holds at all delays from 200 msec. to 2 sec.

Thus, visual very-short-term memory must be considered to be a nonassociative memory. If 2 sec. was sufficiently long to include a large asymptotic memory component, then the present results indicate that asymp-

TABLE 1

PROBABILITY OF CORRECT RECALL

Group	Delay (in sec.)					
	.2	.3	.5	.7	1	2
1 ($n=6$)	.77	.75	.71	.65	.56	.50
2 ($n=2$)	.40	.46	.47	.49	.52	.45

totic memory is nonassociative also. However, since asymptotes were not reached for most Ss in the present experiment, any conclusion regarding tachistoscopic asymptotic memory must be tentative. Furthermore, the input to asymptotic memory might involve a scanning of the characters in a manner other than left-to-right order within a row. In this case, there might be associations formed between adjacently scanned characters which would not be demonstrated by the present study.

It is tempting to speculate that all visual memory is nonassociative, at least in part, but the present results do not apply to any other type of memory than visual very-short-term memory and maybe tachistoscopic asymptotic memory. It is at least equally likely, a priori, that tachistoscopic memory is a very special type of memory and that all other human memory is associative.

In any event, it seems likely that longer term visual memory is associative to the extent that the internal representations of certain concepts (cues) are associated to all of the elements of any retrievable long-term visual image. Nevertheless, it might be a distinctive characteristic of visual memory that the elements of such an image have no associations among themselves.

Since there were no significant differences between the two cueing conditions, the cueing conditions were combined for the determination of the retention functions. The Ss fell into two subgroups; six of the eight Ss showed substantial decreases in memory with increasing delay from 200 msec. to 2 sec. That is to say, six of the eight Ss demonstrated a visual very-short-term memory component which was decaying at about the same relatively slow rate as found by Averbach and Sperling (1961) for the dark pre-

field and postfield condition. However, despite the S selection procedure and the dimly illuminated, low-contrast cue character, two of the eight Ss demonstrated no very-short-term memory component over the range from 200 msec. to 2 sec. The averaged results for these two subgroups are presented in Table 1.

The Ss were required to give some answer on every trial, and the intrusion errors were divided into four categories: (a) the character above or below the correct character in the array, (b) another character in the array from the same conceptual class (letter or digit) as the correct character, (c) a character not in the array from the same conceptual class as the correct character, and (d) a character from the other conceptual class. The last category of error occurred in only two instances (.1% of all intrusion errors), so such errors can be ignored. The relative frequencies of each of the first three categories of intrusions summed over all Ss and all conditions were 20%, 47%, and 33%, respectively. If intrusions had been chosen randomly from the correct conceptual class of characters, the relative frequencies would have been 8%, 31%, and 61%, respectively. Clearly, there is a much greater tendency to recall characters from other positions in the array than to recall characters which were not presented in the array. The present findings also indicate that characters from positions close to the cued position are more likely to be recalled than characters from more remote positions.

Recognition Experiment

Correct "yes" responses averaged 85%; correct "no" responses averaged 81%. Thus, recognition performance was far above chance. It was even greater than the average percentage of correct recall for the same seven Ss, which was 69%. However, the percentages for recognition and recall cannot be compared directly because they are not corrected for the differential probability of correct guessing. The best motivated such correction for guessing is to compare the d' values for both recognition and recall in the manner described by Norman and

Wickelgren (1969). Accordingly, d' values were determined for each S for recognition and recall and then averaged, yielding an average d' for recognition of 2.45 and average d' value for recall of 2.69.

A number of simplifying assumptions were made in determining these d' values. Some of these are known to be false, though the effects of making these false assumptions are probably small. Furthermore, the recognition set was always given at the same stage of practice, viz., between the second and third recall sets, giving rise to the possibility of some differences in level of practice between the recognition and recall tests. Thus, one cannot conclude from the present data that recognition and recall are either equivalent or nonequivalent for tachistoscopic memory. However, it is overwhelmingly clear that a low contrast, dimly illuminated test character does not disrupt to any substantial extent the memory trace for the position on which it is superimposed.

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