SHORT-TERM MEMORY FOR REPEATED AND NON-REPEATED ITEMS

BY

WAYNE A. WICKELGREN

From the Psychology Department, Massachusetts Institute of Technology

Digit sequences containing repeated items are retained differently in short-term memory from sequences containing no repeated items. The repeated items are remembered better or worse than items in the corresponding positions of "all-different" sequences depending on the number of times the item is repeated, the number of items repeated, the number of items intervening between the occurences of a repeated item, and the position of the repeated items in relation to the beginning and end of the sequence. In every type of repetition studied, except one, memory for the non-repeated items in sequences with repeated items is better than for the corresponding items of all-different sequences. This is true in some cases despite significant specific interference between the (non-repeated) items following the separated occurences of repeated items. The negative effects in memory for repeated items and the positive effects in memory for non-repeated items are greater when the items are presented at the rate of five per sec. than at one per sec., contrary to the hypothesis that differential rehearsal is responsible for these effects. The results are interpreted as supporting an "associative," as opposed to a "non-associative," theory of short-term memory, as this distinction is defined in the paper.

INTRODUCTION

Ranschburg (1902) studied recognition and immediate recall of six-digit sequences exposed simultaneously for one-third of a sec. He found that sequences with no repeated digits in them (e.g. 702156) were recognized and recalled better than sequences with repeated digits (e.g. 654042), the difference being attributable to poorer recognition and/or recall of the repeated digits.

The method of simultaneous presentation with brief exposure emphasizes the role of recognition processes. In order to investigate *memory* for repeated items it is necessary to assure that both repeated and non-repeated items are recognized. This is best achieved by means of successive presentation.

Kleinknecht (1906) and Turley (1906) used successive presentation and found significant inhibition in the recall of repeated digits only when the identical digits were next to each other and found greater inhibition when the run of two identical digits was in the middle of the sequence than when the run was at the ends. Obonai and Tatsuno (1954) and Tatuno (1961) found *facilitation* for runs of two identical digits at any position in the sequence. Obonai and Tatsuno found inhibition only when the repeated items were separated by several intervening items and then only when the repeated items were not both near the ends of the sequence. In the latter case there was facilitation of memory for the repeated items. Resolution of these contradictory findings is made more difficult by the lack of sufficient description in the above studies of the recall procedure and the method of scoring errors. Furthermore, the absence of any statistical analysis of the size of the effects in relation to the variance permits the conclusion that these findings are chance fluctuations.

The first purpose of the present study is to replicate these studies in order to resolve the contradictory findings and to determine whether the effects are due to differential error rates in ordering the items recalled (as Obonai and Tatsuno suggest) or in recalling items, scored irrespective of order.

The second purpose of the study is to investigate the effects of item repetition on memory for the *non-repeated items* in sequences with repeated items. Tatuno reported serial position curves for sequences with runs of two identical digits at the beginning, middle, and end in which there appeared to be some facilitation of memory for the non-repeated digits compared to digits in comparable positions of sequences with no repeated digits, but there was no indication whether the effect was significant. Tatuno obtained interference in memory for non-repeated items in the other sequence he studied where the first and the fifth items were identical in a sequence of eight items, but again there was no estimate of significance. Also, there were only two different examples of each type of sequence, which seems a little too few to control for other differences between the sequences.

The third purpose of the study is to investigate memory for repeated and non-repeated digits in sequences with runs of three identical digits or two runs of two identical digits at various serial positions.

The fourth purpose of the study is to determine how memory for repeated and non-repeated items is affected by presentation rates that allow more or less time for rehearsal.

Method

Experiment 1: *One per sec. rate*

Twenty-six subjects were given sequences of digits of lengths 6, 7, 8, 9, and 10, recorded on tape and presented at the rate of one digit per sec. Subjects had a 20 sec. interval between the end of one sequence and the beginning of the next sequence in which to record, in order, the sequence just heard, leaving blanks to indicate positions for which they could not recall the correct item and did not wish to guess. Subjects were not allowed to write down more items than the sequence contained.

Before the start of the test, subjects were given 21 practice sequences of lengths four to ten with no repeated items. In the test, subjects were given 20 sequences at length 6, then 20 at length 7, . . . , and finally 20 at length 10. The 20 sequences at each length included three that contained no repeated items ("all-different" sequences), and one of each of the following 17 types of sequences containing repeated items:

(ii_{B})	1 digit repeated in a length-2 run at beginning of the sequence	(773519)
(ii_{M})	1 digit repeated in a length-2 run at middle of the sequence	(258830)
(ii_{E})	1 digit repeated in a length-2 run at end of the sequence	(904211)
(iji_{B})	1 digit repeated, separated by a digit at beginning of the sequence	(373068)
(iji_{M})	1 digit repeated, separated by a digit at middle of the sequence	(154596)
(iji_{E})	1 digit repeated, separated by a digit at end of the sequence	(043676)
$(ijki_{B})$	1 digit repeated, separated by 2 digits at beginning of the sequence	(518502)
$(ijki_{M})$	1 digit repeated, separated by 2 digits at middle of the sequence	(903702)
$(ijki_{E})$	1 digit repeated, separated by 2 digits at end of the sequence	(239749)
$(i—i_{BE})$	1 digit repeated, separated by the rest of the sequence	(410894)
$(iijj_{B})$	2 digits repeated in length-2 runs at beginning of the sequence	(995536)
$(ii—jj_{BE})$	2 digits repeated in length-2 runs at the 2 ends of the sequence	(881377)
$(ijij_{B})$	2 digits repeated in mixed pairs at beginning of the sequence	(616180)
$(ij—ij_{BE})$	2 digits repeated in mixed pairs at the 2 ends of the sequence	(760476)
(iii_{B})	1 digit repeated in a length-3 run at beginning of the sequence	(333240)
(iii_{M})	1 digit repeated in a length-3 run at middle of the sequence	(400065)
(iii_{E})	1 digit repeated in a length-3 run at end of the sequence	(294777)

Subject to the constraints specified above, sequences were randomly selected. Also, the sequences were randomly ordered within each block of 20 sequences, subject to the constraint that one of the three all-different sequences appeared in each third of each set of 20. Then a totally new set of 20 sequences at each length was randomly selected, subject to the constraints imposed by the different types of sequences. The second set of sequences was arranged in the reverse order of the first set of sequences at each length to control for any practice effects remaining after the practice series. The first set was given to 13 subjects and the second set to 13 subjects. Subjects were M.I.T. undergraduates recruited from an introductory psychology course.

Experiment 2: *Five per sec. rate*

The procedure was similar to experiment one except that the rate of presentation was five digits per sec. Subjects were given 11 sequences at length 6, then 11 at length 7, . . ., then 11 at length 10, making a total of 55 sequences in each set of sequences. There were three different sets of 55 sequences given to each subject, one set after another, making a total of 165 sequences. The 11 sequences at each length in each set consisted of the all-different sequences, ii_B, iji_B, iji_M, iii_B, iii_E, and $iijj_B$ from experiment one plus the following new types:

(ii_{34})	One run of two identical items in positions 3 and 4 of the sequence	(017752)
(ii_{56})	One run of two identical items in positions 5 and 6 of the sequence	(439600)
(iii_{345})	One run of three identical items in positions 3, 4, and 5 in the sequence	(820004)
($iijjkk_B$)	Three runs of two identical digits at the beginning of the sequence	(774466)

Subject to the constraints specified above, sequences were randomly selected and randomly ordered within each block of 11. Summing over all five lengths, there were 15 different sequences for each of the above 11 types. Subjects were 19 M.I.T. undergraduates from an introductory psychology course.

Results

Experiment 1

The data were analyzed for ordered recall and free recall of individual items and entire sequences. A subject's report of a *sequence* is correct by an *ordered recall* criterion if and only if all items are recalled in the correct order. A subject's report of a *sequence* is correct by a *free recall* criterion if and only if all the items are recalled correctly, irrespective of order. A subject's report of each *item* in a sequence is correct by an *ordered recall* criterion if and only if the correct item is recalled in the correct position. A subject's report of each *item* in a sequence is correct by a *free recall* criterion if and only if it appears anywhere in his report of the sequence in question.

At the one per sec. rate, the 50 per cent. point in ordered recall of entire sequences for these subjects was between length 9 and length 10. There was a very slight practice effect in each block of 20 test sequences as measured by *ordered recall* of items and sequences for the all-different sequences in the first, second, and final third of each block of 20. There was no practice effect in *free recall* of items and sequences.

The Spearman rank order correlation between sequence ordered recall and item ordered recall for the 18 types of sequences was 0·90. The correlation between sequence free recall and item free recall was 0·94. The correlation between sequence ordered and sequence free recall was 0·88, but the correlation between item ordered and item free recall was only 0·76. Since item recall correlates so highly with sequence recall and since analysis by item recall permits decomposition of a sequence into repeated items and non-repeated items, the rest of the paper will consider only item recall statistics.

Table I presents the per cent. error in ordered and free item recall for each sequence type at the one per sec. rate. χ^2 tests were used to provide a rough measure of the significance of differences between the all-different sequence and other sequence types. Since all subjects and all trials for the same subject are pooled, the χ^2 test must be interpreted accordingly.

Sequences with certain types of item repetition are remembered significantly better than all-different sequences, but sequences with other kinds of item repetition are remembered no better and in some cases significantly worse than all-different sequences. A run of three identical items at the beginning, middle, and end of a sequence facilitates short-term memory, but the effect is greater at the beginning than at the middle or at the end. A run of two identical items at the beginning or end facilitates short-term memory, but a run of two in the middle does not. A run of two is always less effective than a run of three at any position. An iji pattern at the beginning of a sequence facilitates short-term memory for the sequence, but iji patterns at other positions and ijki patterns at any position do not. Sequences with the same item at the beginning and end (i—i$_{BE}$) are remembered significantly *worse* than all-different sequences. Sequences beginning with iijj and ijij patterns are remembered better than all-different sequences or sequences beginning with ii patterns. Sequences with the repeated items divided between the beginning and the end (ii—jj$_{BE}$ and ij—ij$_{BE}$) are remembered no better than all-different sequences. In fact, ij—ij$_{BE}$ is almost significantly worse than the all-different sequence at the 0·05 level.

TABLE I

Average Error Rate for Items from Different Sequence Types

(One per sec. rate)

Type	*Ordered Recall*			*Free Recall*		
	Per cent	*Sign*	*p*	*Per cent*	*Sign*	*p*
A.D.	11·86			4·46		
ii$_B$	8·27	+	**	2·88	+	*
ii$_M$	11·15	+		4·90	—	
ii$_E$	8·08	+	**	3·85	+	
iji$_B$	8·85	+	**	3·46	+	
iji$_M$	11·15	+		4·33	+	
iji$_E$	11·06	+		5·10	—	
ijki$_B$	12·50	—		4·71	—	
ijki$_M$	11·54	+		5·00	—	
ijki$_E$	12·02	—		3·75	+	
i—i$_{BE}$	14·71	—	*	5·96	—	*
iijj$_B$	6·63	+	***	2·88	+	*
ii—jj$_{BE}$	11·06	+		5·38	—	
ijij$_B$	7·21	+	***	1·73	+	*
ij—ij$_{BE}$	14·13	—		5·00	—	
iii$_B$	3·65	+	***	0·96	+	*
iii$_M$	5·38	+	***	3·08	+	
iii$_E$	9·04	+	*	3·75	+	

A.D. = All-different sequence.
Sign = Algebraic sign of the difference in error rate from A.D. sequences.
p = Probability of difference in error rate from A.D. sequences.
Two-Tailed Chi Square Test: * = 0·05, ** = 0·01, *** = 0·001.

At this point we have established the effects of item repetition on the error rate for items, averaged over all items (repeated and non-repeated) in the sequence. In each comparison of sequences having repeated items with the all-different sequence, two further questions must be asked: (1) What is the error rate for only the repeated items as compared to the error rate for items in the identical positions in the all-different sequence? (2) What is the error rate for the non-repeated items in sequences with repeated items as compared to the error rate for the (non-repeated) items in identical positions in the all-different sequences?

To answer these questions it is necessary to compute the ordered and free recall error rates separately for repeated and non-repeated items. Prior studies of short-term memory for repeated items have reported only ordered recall statistics. Unfortunately, ordered recall scoring contains certain statistical artefacts favouring sequences with repeated items. One artefactual advantage of sequences with repeated items is that there can be no transposition error between repeated items. Another advantage is that a run of identical items that is displaced in recall by one from its correct position, still has n-l of its items in correct positions, whereas a sequence of non-identical items displaced by one in recall has none of its items in correct positions. Therefore, the ordered recall data in Table I should be interpreted with caution.

Tables II and III report the error rates *separately* for repeated and non-repeated

TABLE II

Error Rate for Repeated Items Compared to Identical Positions in A.D. Sequences

(One per sec. rate)

Type	*Free Recall* (*Per cent.*)				*Position Recall* (*Per cent.*)			
	R.I.	*A.D.*	*Sign*	*p*	*R.I.*	*A.D.*	*Sign*	*p*
ii$_{B}$ ..	1·15	4·23	+	*	1·56	6·37	+	
ii$_{M}$ ..	6·15	3·59	—		6·03	11·54	+	
ii$_{E}$ ..	1·54	1·15	—		0·00	5·26	+	*
iji$_{B}$ ..	4·23	4·36	+		3·33	10·16	+	*
iji$_{M}$ ..	7·31	4·62	—		8·18	12·04	+	
iji$_{E}$ ..	6·15	2·82	—	*	5·26	8·72	+	
ijki$_{B}$ ..	5·77	3·85	—		8·55	10·74	+	
ijki$_{M}$ ..	9·62	5·64	—	*	8·33	12·96	+	
ijki$_{E}$ ..	4·62	2·44	—		7·89	9·97	+	
i—i$_{BE}$ ..	4·62	1·28	—	**	2·54	1·32	—	
iijj$_{B}$ ..	4·23	5·06	+		1·72	7·62	+	*
ii—jj$_{BE}$ ..	5·38	2·69	—	**	4·76	9·69	+	
ijij$_{B}$ ..	1·35	5·06	+	***	4·03	8·85	+	
ij—ij$_{BE}$ ..	5·00	2·69	—	*	8·93	9·69	+	
iii$_{B}$ ..	1·54	4·96	+	**	0·00	7·14	+	**
iii$_{M}$ ..	3·33	4·36	+		3·39	9·17	+	
iii$_{E}$ ..	2·05	2·56	+		0·00	7·71	+	**

R.I. = Sequences with repeated items.

Position Recall is independent of free recall and free of artefacts.

Sign = Algebraic sign of difference in error rate between repeated items and comparable items from A.D. sequences.

p = Probability of difference in error rate between repeated items and comparable items from A.D. sequences. (Two-Tailed Chi Square Test: * = 0·05, ** = 0·01, *** = 0·001.)

items in comparison with items in the identical positions in the all-different sequences. Free recall error rates are computed the same as before, but "position recall" error rates are a new way of scoring ordered recall that is free of artefactual advantages for repeated items and statistically independent of the free recall data. Independence from the free recall data is achieved by scoring for correct position in the sequence *only* the items that are recalled correctly by a free recall criterion. For position recall comparisons with *repeated* items, comparable items from the all-different sequences are scored as an entire *set*, all of whose members must be in the correct *set of positions* in the sequence in order to be correct, but within the set itself transposition errors do not count as errors. Naturally the repeated items are scored the same way for position recall. For example, by this new position recall scoring procedure the repeated items from a sequence beginning with a run of three 4's (444 . . .) are counted as either correct or incorrect depending on whether or not all three 4's are recalled in the first three positions. An all-different sequence beginning with 413, scored in a comparable way, is also counted as either correct or incorrect depending on whether or not 4 and 1 and 3 are all recalled in the first three positions. Notice that is is not necessary that the order of recall be 413 . . . ; any transposition of these three numbers in the first three positions is equally correct. Position recall comparisons of *non-repeated* items from sequences with and without repeated items do not require scoring as a set to avoid artefacts, and therefore in this case an individual item is scored as correct or incorrect depending on whether it was recalled in the correct or incorrect position in the sequence.

TABLE III

ERROR RATE FOR NON-REPEATED ITEMS IN SEQUENCES WITH REPEATED ITEMS AND IN A.D. SEQUENCES

(One per sec. rate)

Type	*Free Recall* (*Per cent.*)				*Position Recall* (*Per cent.*)			
	R.I.	*A.D.*	*Sign*	*p*	*R.I.*	*A.D.*	*Sign*	*p*
ii$_B$ ..	3·46	4·53	+		6·77	9·00	+	
ii$_M$ ..	4·49	4·74	+		6·71	6·55	—	
ii$_E$ ..	4·62	5·56	+		5·91	9·46	+	***
iji$_B$ ..	3·21	4·49	+		6·49	8·50	+	
iji$_M$ ..	3·33	4·40	+		7·03	6·79	—	
iji$_E$ ..	4·74	5·00	+		7·40	8·86	+	
ijki$_B$ ..	4·36	4·66	+		9·38	8·38	—	
ijki$_M$ ..	3·46	4·06	+		7·04	7·22	+	
ijki$_E$ ..	3·46	5·13	+		9·96	8·60	—	
i—i$_{BE}$ ..	6·41	5·51	—		12·05	10·22	—	
iijj$_B$ ..	1·53	3·85	+	*	6·25	8·27	+	
ii—jj$_{BE}$ ..	5·38	6·22	+		10·77	12·24	+	
ijij$_B$ ..	2·12	3·85	+	*	8·64	8·27	—	
ij—ij$_{BE}$ ..	5·00	6·22	+		16·40	12·24	—	*
iii$_B$ ..	0·62	4·15	+	***	4·33	8·77	+	***
iii$_M$ ..	2·92	4·51	+		3·01	5·80	+	**
iiii$_E$ ..	4·77	5·59	+		8·89	9·56	+	

Position Recall is independent of free recall.

Sign = Algebraic sign of difference in error rate between non-repeated items in sequences with repeated items and comparable items from A.D. sequences.

p = Probability of difference in error rate between non-repeated items in sequences with repeated items and comparable items from A.D. sequences. (Two-Tailed Chi Square Test: * = 0·05, ** = 0·01, *** = 0·001.)

Perhaps the most striking fact is that free recall memory is very much better for repeated items in certain sequences (ii$_B$, ijij$_B$, and iii$_B$) than comparable items in the all-different sequences and very much worse for repeated items in other sequences (iji$_E$, ijki$_M$, i—i$_{BE}$, ii—jj$_{BE}$, and ij—ij$_{BE}$) than comparable items in the all-different sequences. It appears that memory for the repeated items is better for runs of three than for runs of two, better when fewer items separate the occurrence of the repeated item(s) and better for repetitions occurring near the beginning of the sequence. It is reasonable to conjecture that these conditions favour recoding of a run or simple repetition-pattern into one chunk, or at least fewer chunks than the number of items in the run or repetition-pattern. Of even greater interest is the finding that when conditions are (presumed to be) unfavourable for recognition of the repetition and recoding into fewer chunks, repeated items are remembered worse than comparable non-repeated items.

In 16 out of 17 comparisons, position recall is better for repeated items than for comparable items in the all-different sequences. Since position recall is computed only for those items recalled correctly by a free recall criterion, this further supports the hypothesis that when the repetition is recognized and recoded by the subject the repeated items are remembered better than the comparable non-repeated items.

In 16 out of 17 cases, free recall memory for comparable non-repeated items is better in sequences with repeated items than in sequences without repeated items. It appears that repeated items produce less interference with the rest of the items in the sequence than comparable non-repeated items. This is true regardless of whether the repeated items are remembered better or worse than comparable non-repeated items from the all-different sequence. The only consistent exception to this generalization is $i—i_{BE}$.

Position recall is superior for non-repeated items from sequences with repeated items in only 10 comparisons out of 17; three comparisons are significant in one direc-direction, and one in the opposite direction. No simple explanation accounts for the pattern of relationships. The reduced interference from repeated items on the recall of non-repeated items is measured primarily in superior recall of items, not in superior recall of position.

For reasons that will be explained in the discussion, let us consider the kinds of intrusion errors made in place of the item *following* (correctly recalled) repeated items in the following sequences: iji_B, iji_M, $ijki_B$, and $ijki_M$. We are concerned with how often this intrusion error is the item that followed the *other* occurence of the repeated item in the *presented* sequence. For example, in the sequence ijikl . . . we are interested in the frequency of putting k in place of j in the second position and the frequency of putting j in place of k in the fourth position, compared to the frequency of all other intrusion errors at these positions in these sequences. Call this type of intrusion an "associative intrusion." Averaging over all four sequence types mentioned above, associative intrusions occurred 16 times out of a total of 50 intrusion errors, or 32 per cent. of all intrusion errors in these positions. Scoring intrusion errors into the same two categories in the all-different sequence, we obtain 27 intrusions comparable to the associative intrusions, out of a total of 143 intrusions of all types, or 19 per cent. of all intrusions in these positions. Scoring the all-different sequence in the same way provides an estimate of how frequently the items in the positions with which we are concerned would be substituted for each other, even when they did not follow identical items. The difference between 32 per cent. and 19 per cent. just misses significance at the 0·05 level ($\chi^2 = 3{\cdot}68$), providing some support for the hypothesis that items following repeated items are more likely to be substituted for each other in recall than items following comparable non-repeated items.

Experiment 2

At the five per sec. rate, the 50 per cent. point in ordered recall of entire sequences was almost exactly at length 8. Error rates in ordered and free item recall of each sequence type are presented in Table IV. All 10 types of sequences with repeated items are remembered better than the all-different sequences by ordered recall scoring. By free recall scoring, ii_B, iji_B, iii_B, and iii_E are remembered significantly better than the all-different sequence, while iii_{345} is remembered significantly worse.

Tables V and VI report the free recall and position recall error rates for repeated and non-repeated items in comparison with items in the identical positions in the all different sequences.

Free recall memory for repeated items is significantly better than for comparable items in the all-different sequence in only one case, ii_B. Free recall memory for repeated items is significantly worse in five cases: ii_{34}, ii_{56}, iii_{345}, $iijjkk_B$, and iji_M. As at the one per sec. rate, memory for items is also much better for some sequences and much worse for other sequences than memory for items at identical positions in the all-different sequences. At both rates, repeated items in the middle show the greatest decrement in recall. At both rates, it appears that repeated items are remembered worse when they are separated by other items than when they are together in a run.

TABLE IV

AVERAGE ERROR RATE FOR ITEMS FROM DIFFERENT SEQUENCE TYPES

(Five per sec. rate)

Type	*Ordered Recall*			*Free Recall*		
	Per cent.	*Sign*	*p*	*Per cent.*	*Sign*	*p*
A.D.	24·28			7·83		
ii_B	19·44	+	***	4·90	+	***
ii_{34}	20·74	+	**	9·22	—	
ii_{56}	23·00	+		8·62	—	
iji_B	18·74	+	***	5·10	+	***
iji_M	24·20	+		9·18	—	
iii_B	21·29	+	*	5·58	+	**
iii_{345}	22·52	+		11·43	—	***
iii_E	15·71	+	***	5·12	+	***
$iijj_B$	20·18	+	**	6·91	+	
$iijjkk_B$	16·31	+	***	8·43	—	

Sign = Algebraic sign of the difference in error rate from A.D. sequences.
p = Probability of difference in error rate from A.D. sequences.
(Two-Tailed Chi Square Test: * = 0·05, ** = 0·01, *** = 0·001.)

However, there are some interesting differences between the one per sec. rate and the five per sec. rate. There seems to be a general tendency for repeated items to be remembered worse at the faster rate of presentation than at the slower rate. Runs of three identical items, particularly, are remembered much worse at the faster rate of presentation. At the one per sec. rate, runs of three identical items at the beginning are remembered better than runs of three at the end, but, at the five per sec. rate, just the reverse is true. At the one per sec. rate, runs of three are remembered better than runs of two, but at the five per sec. rate, the reverse is true. The decrement in recall of runs of three identical items at the beginning develops gradually with increasing length of the sequence, and is accounted for completely by a tendency to omit the third item of the run. This tendency increases with sequence length, as the number of items following the run of three increases. At length-6, runs of three identical items at the beginning are remembered better than the three items at the beginning of all-different sequences, but by lengths 9 and 10 the identical items are remembered worse.

Recall of the correct position, for items correctly recalled at some position, is better for repeated items than for the comparable items in the all-different sequences in 10 cases out of ten. In every sequence type except $iijjkk_B$ and iji_M, this effect is significant. In general, repeated items are less likely to be recalled at all, but those that are recalled are more likely to be recalled in the correct position, whether the rate is five per sec. or one per sec.

TABLE V

ERROR RATE FOR REPEATED ITEMS COMPARED TO IDENTICAL POSITIONS IN A.D. SEQUENCES

(Five per sec. rate)

Type	*Free Recall (Per cent.)*				*Position Recall (Per cent.)*			
	R.I.	*A.D.*	*Sign*	*p*	*R.I.*	*A.D.*	*Sign*	*p*
ii_B ..	0·34	3·14	+	***	0·00	9·58	+	***
ii_{34} ..	14·23	7·25	—	***	4·81	22·57	+	***
ii_{56} ..	20·80	10·59	—	***	10·18	26·57	+	***
iji_B ..	2·16	3·53	+		4·51	14·29	+	***
iji_M ..	19·70	9·61	—	***	23·75	47·26	+	
iii_B ..	4·62	4·31	—		6·22	13·22	+	*
iii_{345} ..	19·08	7·84	—	***	10·95	23·19	+	**
iii_E ..	4·14	6·01	+		0·83	17·54	+	***
$iijj_B$ ..	8·67	5·20	—		9·55	19·16	+	*
$iijjkk_B$ ..	9·55	6·99	—	*	7·14	11·05	+	

Position Recall is independent of free recall and free of artefacts.

Sign = Algebraic sign of difference in error rate between repeated items and comparable items from A.D. sequences.

p = Probability of difference in error rate between repeated items and comparable items from A.D. sequences.

(Two-Tailed Chi Square Test: * = 0·05, ** = 0·01, *** = 0·001.)

TABLE VI

ERROR RATE FOR NON-REPEATED ITEMS IN SEQUENCES WITH REPEATED ITEMS AND IN A.D. SEQUENCES

(Five per sec. rate)

Type	*Free Recall (Per cent.)*				*Position Recall (Per cent.)*			
	R.I.	*A.D.*	*Sign*	*p*	*R.I.*	*A.D.*	*Sign*	*p*
ii_B ..	6·48	9·42	+	**	17·29	18·40	+	
ii_{34} ..	7·52	8·02	+		12·59	14·70	+	
ii_{56} ..	4·50	6·90	+	**	14·42	12·69	—	
iji_B ..	6·12	9·28	+	**	15·70	17·64	+	
iji_M ..	5·31	7·23	+		14·13	13·27	—	
iii_B ..	6·16	9·98	+	***	20·59	19·43	—	
iii_{345} ..	6·89	7·82	+		14·20	13·03	—	
iii_E ..	5·71	8·94	+	**	15·10	16·16	+	
$iijj_B$ ..	5·12	10·52	+	***	20·58	19·40	—	
$iijjkk_B$ ..	4·94	10·45	+	**	17·76	16·60	—	

Position Recall is independent of free recall

Sign = Algebraic sign of difference in error rate between non-repeated items in sequences with repeated items and comparable items from A.D. sequences.

p = Probability of difference in error rate between non-repeated items in sequences with repeated items and comparable items from A.D. sequences. (Two-Tailed Chi Square Test * = 0·05, ** = 0·01, *** = 0·001.)

At the five per sec. rate, as at the one per sec. rate, non-repeated items in sequences with repeated items are remembered uniformly better than the comparable (non-repeated) items from the all-different sequence, by a free recall criterion. The effect seems to be even stronger at the five per sec. rate than at the one per sec. rate.

Recall of the correct position, for items correctly recalled at some position, is equally good for non-repeated items in sequences with and without repeated items.

Associative intrusion errors account for 36 out of 94 intrusion errors in the positions following the repeated items in iji_B and iji_M, or 38 per cent. The comparable figures for the all-different sequence are 18 out of 113, or 16 per cent. This difference is significant at the 0·001 level ($\chi^2 = 13{\cdot}32$).

Discussion

Let us consider two basic types of memory systems by which a human being might recall an ordered list of items: an associative memory and a non-associative memory.

We shall define an associative memory to be a memory system satisfying two properties: (1) The internal representative of any *item* (item-rep) is a class of firing patterns always in the *same* set of neurons. (2) The internal representative of the *order* in which the items are presented is a facilitation of the connections between internal-reps. This facilitation of the tendency for one internal-rep to activate another internal-rep depends on the degree of contiguity of activation of the two internal-reps in the past and the time or number of items since last pairing. So long as there is no way to prevent rehearsal, degree of contiguity of the *presented items* measured in time is probably vastly less important than degree of contiguity of the presented items measured in number of intervening items.

There are many different associative memory systems for the ordered recall of an ordered list, all based on the above two properties, but differing in their assumptions concerning what internal-reps are activated during presentation of the list. All associative memory systems must assume that the presented items activate item-reps in the memory, but in addition there may be internal-reps of such ordering concepts as "beginning of the list," "next to the beginning," "middle of the list," "next to the end," and "end of the list," that are activated while the list is presented and therefore become associated to certain items and not to others, or more strongly associated to certain items than to others. Furthermore, there may be internal-reps of certain general context cues (pure free recall cues) that become associated weakly, but more or less equally, to all items in the list. These cues facilitate free recall of items, but provide no order information.

We shall define a non-associative memory to be a memory system satisfying two properties: (1) The internal-rep of an item is a class of firing patterns in *any* sufficiently large set of neurons. (2) The internal-rep of the order in which the items are presented is a *fixed connection* between sets of neurons, each of which is large enough to store the firing pattern that is the internal-rep of an item. When a list of items is presented, the firing pattern representing the first item is impressed on the set of neurons that is the first memory cell, then the firing pattern representing the second item is impressed on the second memory cell, etc. In recall, the system starts at the first memory cell and reads its firing pattern, then goes to the second memory cell and reads its firing pattern, etc. It should be mentioned that the trace that is stored in a memory cell need not be active—that is, it may be a change in the synapses that lasts until read-out, not a reverberating firing pattern. In the passive-trace version of the non-associative memory theory, read-out might consist of putting some diffuse input into a memory cell and reading the firing pattern that develops as a result of the passive trace.

The large amount of specific interference between the two different items following the separated occurrences of a repeated item in a list is compelling support for an associative theory of short-term memory. In an associative memory, the internal-rep of the repeated item should be associated to the internal-reps of both succeeding items, and this ought to produce an above chance frequency of associative intrusion errors. In a non-associative memory there is no natural reason for this interference.

The second finding that supports an associative theory of short-term memory is the decrement in the free recall of repeated items in all cases except those most favourable to the recognition and recoding of the repetition. For a non-associative memory, in the absence of recognition and recoding of repeated items, memory for the repeated items should be the same as for comparable non-repeated items. However, for an associative memory there is only one internal-rep of an item, and if both occurrences of the item are not correctly recalled in order, free recall cues will provide only the information that the item was presented, not that it was presented twice.

The fact that certain patterns of repeated items are remembered better than items in the corresponding positions of all-different sequences is evidence for a recoding mechanism in short-term memory. This means that three successive activations of an item-rep activates the internal-rep of "run-of-three—s" which is parameterized at the — by the item that was repeated. This eliciting of new concepts by association to certain patterns of input stimulation is part of the essence of an associative memory. With a non-associative theory of short-term memory, this eliciting of new concepts and recoding must be done by another system separate from the non-associative short-term memory system. This may be how it is done, but such a combination of systems is certainly a less elegant, less parsimonious theory.

When repeated items are recoded into a single internal-rep, such as "run-of-three —s," and thus remembered better, the fact that short-term memory for the non-repeated items is also better can be easily predicted by both associative and non-associative theories. Recoding effectively shortens the list in terms of the number of internal-reps that are needed to encode the list.

When repeated items are not recoded and are then remembered worse than non-repeated items, the facilitation of memory for the non-repeated items is very hard to explain with a non-associative memory theory. With an associative memory in which the interference between items is a function of the number of *different item-reps* activated, this result is very easily explained because lists with one repeated item activate one less different item-rep and thus generate less interference.

Assuming that human short-term memory is associative, what further information about the system is provided by this experiment?

The fact that memory for the items following the separated occurrences of repeated items is not disasterously impaired is evidence for the existence of some kind of serial order cues (such as: beginning, next to beginning, middle, next to end, end) in addition to prior-item cues for the ordered recall of ordered lists.

The fact that free recall of items and ordered recall of items are not perfectly correlated is evidence for a set of general context (free recall) cues associated to all items, or some other mechanism for determining if an internal-rep has been activated recently.

The findings of these experiments have been interpreted as evidence for the associative nature of short-term memory. However, an alternative explanation for the above findings might be advanced in terms of a cognitive strategy of rehearsal and recoding that would predict the same findings and would invalidate these findings as evidence for the associative nature of short-term memory.

Another line of attack on the interpretation that short-term memory is associative is to limit the generality of the interpretation by questioning, "How short is short?" A 10-item sequence presented at one item per sec. takes 9 sec. to present. Is memory for 10 items presented in 9 sec. the shortest of short-term memories or is there a totally different type of memory for 10 items presented in a much shorter period of time?

The second experiment was performed to provide some evidence on both of these questions. Any strategy explanation of the one per sec. findings should predict that the findings would be less significant when the subject had less time to implement whatever strategy he was assumed to be employing. However, the three findings that are most compelling in support of an associative theory of short-term memory, namely, (1) the negative effects in free recall memory for repeated items, (2) the positive effects in free recall memory for non-repeated items in sequences with repeated items, and (3) the above chance incidence of associative intrusions, are all more significant at the faster rate of presentation than at the slower rate of presentation. Strategies of rehearsal and recoding tend to diminish these findings, not enhance them.

Selective attention to items *different* from those items previously heard might account for part of the decrement in recall of repeated items. By this hypothesis subjects might fail to *hear* repeated items more often than non-repeated items. This hypothesis is almost certainly false at the one per sec. rate, but at the five per sec. rate it is certainly possible. At the five per sec. rate the third item of a run of three identical items at the beginning tends to be omitted, and at first glance, this fact seems to argue that perhaps subjects do not hear all three items. However, runs of three identical items at the beginning are remembered even better than comparable non-identical items in shorter length sequences. Only when the sequence gets longer do they tend to omit the third item of a run of three identical items at the beginning. This argues that the locus of the effect is in memory, not in attention. The tentative explanation offered here is that, at the faster speed, runs of three at the beginning do not have as much time to be recoded as "run-of-three —'s" and are therefore less often recoded than at the slower speed. When repeated items are not recoded into a new concept, they are remembered worse than non-repeated items according to the hypothesis that short-term memory is associative.

The results of the second experiment in conjunction with the first experiment make it appear unlikely that strategy explanations (such as rehearsal, recoding, or selective attention) are responsible for the findings in short-term memory for repeated and non-repeated items. If strategy explanations are invalid, the results of these two experiments argue strongly that short-term memory is associative rather than non-associative, even short-term memory as short-term as 10 items presented in 2 sec.

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