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NUMERICAL RELATIONS, SIMILARITY, AND SHORT-TERM RECOGNITION MEMORY FOR PAIRS OF DIGITS

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Recognition memory for pairs of digits after a 6 sec interference task was superior for pairs containing a zero or one and for pairs consisting of two identical digits than for 'ordinary' pairs. Pairs consisting of digits in forward or backward sequence (e.g. 56 or 43) and pairs where one digit is a multiple of the other were remembered slightly better than 'ordinary' pairs. False recognition rates were highest for test pairs that had the highest degrees of 'identical elements' similarity to the presented pair (two identical digits in reversed positions or one identical digit in the same position as in the presented pair). The results are discussed in terms of an associative theory of short-term recognition memory.

Most people feel intuitively that pairs of digits such as 44, 67, 32, 84 are easier to remember than pairs of digits such as 37, 85, 92, 83. The first set consists of pairs whose digits have some familiar numerical relationship to each other—identity (44), forward numerical order (67), backward numerical order (32), multiple (84). The second set consists of pairs whose digits have no universally familiar relationship.

There are some studies on short-term recall of lists of six to ten items containing runs of identical items (44, 999, etc.) by Ranschburg (1902), Kleinknecht (1906), Turley (1906), Obonai & Tatsuno (1954), Tatuno (1961), and Wickelgren (1965). These studies suggest that a run of two identical digits is easier to remember than two different digits, but this result is affected by the position of the run in the list and the speed of presentation. Furthermore, these experiments all used lists much longer than two. There are apparently no studies on short-term memory for pairs whose digits have numerical relations other than identity.

Although one's first intuition is that pairs with familiar relations ought to be easier to remember than pairs without familiar relations, it is not easy to justify this conclusion theoretically. It is true that, if the relation is recognized, one can recode a pair of digits into one digit and a relation but, in English, this seems always to require as many or more 'words' than merely storing the two digits without recoding. It might also be claimed that the activity of counting forwards and backwards by ones, twos, threes, and so on, has differentially strengthened the associations between certain digits and not others. However, much the greater part of our experience with digits does not consist of counting, and any differences in the frequency of experiencing different pairs in sequence must be very small in relation to the total frequency of exposure to each pair. Existing data suggest that verbal learning is a negatively accelerated function of frequency of past experience (Underwood & Schulz, 1960), which implies that large differences in absolute frequency of past experience make little difference, once the absolute frequency of past experience is large. Even the most infrequent pair of digits has been experienced a gigantic number of times by the average college student. Thus it is by no means obvious that pairs with familiar relations will be easier to remember than pairs without familiar relations.

An experiment on letter–number paired associate learning by Williams (1961) suggested that some pairs of digits may be easier to remember than others, but the categorization of digit pairs was not on the basis of numerical relations. Williams found evidence that numbers from 1 to 15 were easier to remember than numbers from 16 to 50. Since the numbers from 1 to 9 were presented as single digits rather than as pairs, 01, . . ., 09, it is not clear whether this result reflects anything beyond the greater ease of remembering one digit than two digits. However, the fact that Williams included the pairs 10–15 in the 'easy' group argues that perhaps pairs beginning with 0 and 1 are easier than pairs containing no 0 or 1. Maybe pairs ending in 0 or 1 are also easier than pairs containing no 0 or 1. Again, it is not obvious that this should be so on the basis of either recoding or past experience, for reasons completely analogous to those stated in the previous paragraph.

The first objective of the present study was to determine if some types of digit pairs are easier to remember than other types of digit pairs, and, if so, which types. The second objective was to determine if a recognition memory test pair that is 'similar' to the originally presented pair in some way will produce a higher frequency of false recognition than a test pair that is less similar. There are many ways in which the test pair might be similar to the pair originally presented, such as, for instance, possessing one or two common digits in the same or different positions, or possessing the same type of numerical relation between the digits in the pair. To the extent that the memory trace for a pair of digits is composed of at least semi-independent traces for its component digits and their relations, it should be possible to demonstrate a higher frequency of false recognition for test pairs that have some features in common with the presented pair. If the memory trace for a pair, such as 95, is a completely additive combination of separate traces for 9 and for 5 and for 'decreasing order' or a completely additive combination of separate traces for 9 in the first position and 5 in the second position, then the false recognition rate for highly similar test pairs ought to be an appreciable fraction of the correct recognition rate. If the memory trace for a pair is highly super-additive to the point of being a completely contingent association—that is, the trace for '95' is not the sum of any set of traces for the component properties of '95', then there should be no difference in false recognition frequency for more or less similar test pairs.

Method

Experiment I

Procedure

On each trial a ready signal was followed after 1 sec by a pair of digits to be copied during the second in which the pair was presented and the 0·5 sec interval that followed (filled with a tone). Immediately after the tone, twelve randomly selected interference digits were presented at the rate of 0·5 sec/digit; subjects were to copy these as they were being presented. Immediately after the interference task, a tone sounded for about 0·5 sec, followed by a recognition test pair of digits, which was also to be copied. Subjects were then given 10 sec in which to decide whether the test pair was identical with the presented pair or not and to indicate their confidence in this decision on a five-point rating scale. The subjects' label for these decisions was 'yes' or 'no', respectively. Naturally, subjects were instructed to cover what they had copied for the originally presented pair immediately after copying the presented pair. The purpose of requiring subjects to copy the originally presented pair was to ensure that subjects paid attention to the pair to the point of correct recognition and to limit the time available for rehearsal of the pair by forcing subjects to make responses during the presentation of the pair. Each trial required a total of about 20 sec. The entire experiment was recorded on tape and administered to groups of about thirteen subjects each. The experiment lasted about 1 hr.

Design

There were thirty-one conditions in the experiment, differing in the nature of the presented pair and in the similarity of the test pair to the presented pair. The order of presenting the conditions was randomized in blocks of thirty-one trials, and there were five blocks in the experiment for a total of 155 trials. The complete list of the thirty-one conditions is given in Table 1. Subjects were thirty-eight M.I.T. undergraduates who participated in the experiment to fulfil a requirement of their psychology courses.

Table 1. *Conditions in Experiment I*

Condition	Type presented pair	Type of test pair	Relation of test pair to presented pair
$(XX; XX)$	I	I	Identical
$(XX; YY)$	I	I	No common items
$(XX; XY)$	I	NCR	First item identical. Second different
$(XX; YZ)$	I	NCR	No common items
$(mX, nX; mX, nX)$	M	M	Identical
$(mX, nX; nX, mX)$	M	M	Identical items in reverse order
$(mX, nX; jY, kY)$	M	M	No common items
$(mX, nX; mX, Y)$	M	NCR	First item identical
$(mX, nX; Y, Z)$	M	NCR	No common items
$(X, X+1; X, X+1)$	FO	FO	Identical
$(X, X+1; X+1, X)$	FO	BO	Identical items in reverse order
$(X, X+1; Y, Y+1)$	FO	FO	No common items
$(X, X+1; X, Y)$	FO	NCR	First item identical
$(X, X+1; Y, Z)$	FO	NCR	No common items
$(X, X-1; X, X-1)$	BO	BO	Identical
$(X, X-1; X-1, X)$	BO	FO	Identical items in reverse order
$(X, X-1; Y, Y-1)$	BO	BO	No common items
$(X, X-1; X, Y)$	BO	NCR	First item identical
$(X, X-1; Y, Z)$	BO	NCR	No common items
$(XY; XY)$	NCR	NCR	Identical
$(XY; YX)$	NCR	NCR	Identical items in reverse order
$(XY; XZ: S)$	NCR	NCR	First item identical: same order
$(XY; XZ: D)$	NCR	NCR	First item identical: different order
$(XY; ZX: S)$	NCR	NCR	Second item of test is first item of presented pair: same order
$(XY; ZX: D)$	NCR	NCR	Second item of test is first item of presented pair: different order
$(XY; ZY: S)$	NCR	NCR	Second item identical: same order
$(XY; ZY: D)$	NCR	NCR	Second item identical: different order
$(XY; YZ: S)$	NCR	NCR	First item of test is second item of presented pair: same order
$(XY; YZ: D)$	NCR	NCR	First item of test is second item of presented pair: different order
$(XY; WZ: S)$	NCR	NCR	No common items: same order
$(XY; WZ: D)$	NCR	NCR	No common items: different order

Note. I stands for a pair of identical digits such as 44. M stands for two digits that are multiples of a digit $\geqslant 2$, such as 68, 24, or 39. FO stands for two digits in forward numerical order, such as 56. BO stands for two digits in backward numerical order, such as 87. NCR stands for two digits that have 'no common relation', which means the pair is not I, M, FO, or BO. $(XY: WZ)$ are in the 'same order' if and only if $(X > Y$ implies $W > Z)$ and $(X < Y$ implies $W < Z)$. 'Different order' is the reverse of 'same order'.

Experiment II

Procedure

The procedure differed from the first experiment in only one way. In the second experiment, subjects were required to copy four proactive-interference (PI) digits before being presented with the pair to be remembered later. The four PI digits were presented at the rate of 0·5 sec/digit, and were followed immediately by the presented pair, which was copied as in the first experiment. The purpose of including the PI digits in this experiment was to increase the error rate, which is low for recognition memory of a single pair of digits.

Table 2. *Conditions in Experiment II*

Condition	Type of presented pair	Type of test pair	Relation of test pair to presented pair
(*XX*; *XX*)	*I*	*I*	Identical
(*XX*; *YZ*)	*I*	*NCR*	No common items
(*X*, *nX*; *X*, *nX*)	*M*	*M*	Identical
(*X*, *nX*; *YZ*: *S*)	*M*	*NCR*	No common items: same order
(*X*, *X*+*1*; *X*, *X*+*1*)	*FO*	*FO*	Identical
(*X*, *X*+*1*; *YZ* : *S*)	*FO*	*NCR*	No common items: same order
(*X*, *X*−*1*; *X*, *X*−*1*)	*BO*	*BO*	Identical
(*X*, *X*−*1*; *YZ*: *S*)	*BO*	*NCR*	No common items: same order
(*XY*; *XY*)	*NCR*	*NCR*	Identical
(*XY*; *ZZ*)	*NCR*	*I*	No common items
(*XY*; *Z*, *nZ*: *S*)	*NCR*	*M*	No common items: same order
(*XY*; *Z*, *Z*+*1*: *S*)	*NCR*	*FO*	No common items: same order
(*XY*; *Z*, *Z*−*1*: *S*)	*NCR*	*BO*	No common items: same order
(*XY*; *XZ*: *S*)	*NCR*	*NCR*	First item identical: same order
(*XY*; *ZY*: *S*)	*NCR*	*NCR*	Second item identical: same order
(*XY*; *WZ*: *S*)	*NCR*	*NCR*	No common items: same order
(*XY*; *WZ*: *D*)	*NCR*	*NCR*	No common items: different order
(*XY*; *0Z*: *S*)	*NCR*	*0X*	No common items: same order
(*XY*: *Z0*: *S*)	*NCR*	*X0*	No common items: same order
(*XY*; *1Z*: *S*)	*NCR*	*1X*	No common items: same order
(*XY*; *Z1*: *S*)	*NCR*	*X1*	No common items: same order
(*0X*; *0X*)	*0X*	*0X*	Identical
(*0X*; *YZ*: *S*)	*0X*	*NCR*	No common items: same order
(*X0*; *X0*)	*X0*	*X0*	Identical
(*X0*; *YZ*: *S*)	*X0*	*NCR*	No common items: same order
(*1X*; *1X*)	*1X*	*1X*	Identical
(*1X*; *YZ*:*S*)	*1X*	*NCR*	No common items: same order
(*X1*; *X1*)	*X1*	*X1*	Identical
(*X1*; *YZ*: *S*)	*X1*	*NCR*	No common items: same order

Note. *I*, *M*, *FO*, *BO*, and *NCR* have the same meanings as in Table 1, except that *W*, *X*, *Y*, and *Z* cannot be 0 or 1 and *M* is restricted to multiples of 2 or 4 where one member of the pair is also a multiple of the other, such as 24, 42, 28, 82, 48, 84. (*X*, *nX*) is only a convenient abbreviation for (*X*, *nX* or *nX*, *X*). *0X* means an *NCR* pair in which zero is the first element. *X0*, *1X*, and *X1* are completely analogous.

Design

There were thirty-one conditions in the second experiment also, but most of the conditions were somewhat different from those in the first experiment. The order of presenting the conditions was randomized in blocks of thirty-one trials, and there were again five blocks of trials, as in Expt I. Subjects were forty-four M.I.T. undergraduates taking psychology courses. The complete list of conditions is given in Table 2.

Results

On each trial a subject must choose one of ten decision-confidence pairs. Let $i = 1, \ldots, 5, 6, \ldots, 10$ stand for 'yes' with confidence '5' (greatest confidence), ..., 'yes' with confidence '1' (least confidence), 'no' with confidence '1', ..., 'no' with confidence '5': $f_i(x)$ may then represent the total frequency (over all blocks and all subjects) with which response i occurred in condition x;

$$r_i(x) = f_i(x) / \sum_{i=1}^{10} f_i(x)$$

may represent the relative frequency with which response i occurred in condition x; and

$$R_i(x) = \sum_{j=1}^{i} r_i(x)$$

may represent the cumulative relative frequency with which responses 1 to i occurred in condition x. The cumulative relative frequency functions obtained for each condition in Expts I and II are given in Tables 3 and 4, respectively.

Table 3. *Values (%) of $R_i(x)$ in Experiment I*

	$R_i(x)$ in Experiment I										
Condition (x)	$Y5$	$Y4$	$Y3$	$Y2$	$Y1$	$N1$	$N2$	$N3$	$N4$	$N5$	N
$(XX; XX)$	82·6	88·4	90·5	90·5	90·5	91·0	92·1	93·7	94·8	100	190
$(XX; YY)$	0·0	1·1	2·7	3·2	3·2	4·3	5·4	8·6	14·4	100	190
$(XX; XY)$	1·1	1·6	2·7	2·7	2·7	3·2	4·3	6·9	13·2	100	190
$(XX; YZ)$	0·0	0·5	0·5	0·5	0·5	0·5	1·0	5·2	14·1	100	190
$(mX, nX; mX, nX)$	50·5	60·0	68·4	70·5	72·6	75·2	77·3	83·1	88·9	100	190
$(mX, nX; nX, mX)$	0·5	2·1	2·6	3·1	3·1	3·6	5·2	13·1	24·2	100	190
$(mX, nX; jY, kY)$	0·5	0·5	0·5	1·6	1·6	2·1	2·6	9·4	18·3	100	190
$(mX, nX; mX, Y)$	2·1	4·7	6·3	6·3	6·8	7·9	10·5	14·7	28·9	100	190
$(mX, nX; Y, Z)$	0·5	1·6	1·6	2·1	2·6	2·6	3·1	6·3	16·8	100	190
$(X, X+1; X, X+1)$	57·9	69·5	75·8	77·4	77·9	79·5	80·6	86·9	92·2	100	190
$(X, X+1; X+1, X)$	1·1	4·3	7·5	7·5	8·6	8·6	8·6	17·0	29·1	100	189
$(X, X+1; Y, Y+1)$	0·5	0·5	0·5	1·0	1·0	1·0	1·5	4·1	13·6	100	188
$(X, X+1; X, Y)$	0·0	1·1	1·1	1·1	1·6	2·7	4·3	9·6	21·7	100	190
$(X, X+1; Y, Z)$	0·5	1·6	3·7	4·2	4·7	5·2	6·8	10·5	23·7	100	190
$(X, X-1; X, X-1)$	61·6	73·2	80·0	82·6	83·1	84·7	86·3	91·0	94·2	100	189
$(X, X-1; X-1, X)$	1·1	2·2	3·8	4·9	5·4	7·5	9·1	19·1	33·8	100	189
$(X, X-1; Y, Y-1)$	1·1	1·1	2·2	2·2	2·2	4·3	4·8	12·7	24·3	100	190
$(X, X-1; X, Y)$	0·0	0·0	0·5	0·5	0·5	1·0	1·5	4·1	17·8	100	190
$(X, X-1; Y, Z)$	0·0	0·0	0·5	1·0	1·5	2·6	3·1	8·4	20·0	100	190
$(XY; XY)$	58·4	73·1	78·9	79·4	80·5	81·6	84·8	90·6	94·3	100	190
$(XY; YX)$	0·0	1·6	3·2	3·2	3·7	3·7	5·3	16·9	30·6	100	190
$(XY; XZ: S)$	2·6	4·7	6·3	6·8	6·8	7·3	8·9	12·6	24·2	100	190
$(XY; XZ: D)$	1·1	1·6	2·1	3·2	3·2	3·2	4·8	12·2	24·3	100	190
$(XY; ZX: S)$	0·0	0·5	1·0	1·0	1·0	1·5	2·0	10·9	21·4	100	190
$(XY; ZX: D)$	0·5	0·5	2·1	2·1	2·6	5·2	6·8	9·4	19·4	100	188
$(XY; ZY: S)$	3·2	6·4	9·0	11·1	11·1	12·2	14·3	22·2	34·3	100	190
$(XY; ZY: D)$	1·1	1·6	3·7	4·8	6·4	8·5	10·1	12·7	28·5	100	189
$(XY; YZ: S)$	1·1	1·1	2·2	2·2	2·2	3·3	4·4	8·1	20·7	100	190
$(XY; YZ: D)$	0·0	0·0	0·5	1·0	1·5	2·0	3·6	5·7	19·9	100	190
$(XY; WZ: S)$	0·0	2·1	3·2	3·2	3·7	5·8	6·3	11·6	20·5	100	190
$(XY; WZ: D)$	0·5	0·5	1·0	1·5	1·5	2·0	4·6	9·9	24·6	100	190

Similarity of test to presented pair

Same versus different numerical order. There are five pairs of conditions in Expt I [$(XY;\ XZ\colon S)$ versus $(XY;\ XZ\colon D)$, $(XY;\ ZX\colon S)$ versus $(XY;\ ZX\colon D)$, $(XY;\ ZY\colon S)$ versus $(XY;\ ZY\colon D)$, $(XY;\ YZ\colon S)$ versus $(XY;\ YZ\colon D)$, and $(XY;\ WZ\colon S)$ versus $(XY;\ WZ\colon D)$] and one pair of conditions in Expt II [$(XY;\ WZ\colon S)$ versus $(XY;\ WZ\colon D)$] that were designed to determine whether the numerical order of the digits in a pair is an important cue in recognition memory. In the present context, 'numerical order' simply refers to whether the first digit is greater than the second digit, e.g. 95, or vice versa, e.g. 59. On the average, there is a higher false recognition

Table 4. *Values (%) of $R_i(x)$ in Experiment II*

	$R_i(x)$ *in Experiment II*									
Condition (x)	$Y5$	$Y4$	$Y3$	$Y2$	$Y1$	$N1$	$N2$	$N3$	$N4$	$N5$	N
$(XX;\ XX)$	70·4	81·2	83·9	85·6	87·4	87·9	90·1	91·5	91·9	100	223
$(XX;\ YZ)$	0·5	0·5	3·3	3·8	4·2	8·5	12·2	21·1	30·0	100	213
$(X, nX;\ X, nX)$	35·3	47·7	60·8	64·4	67·6	72·7	77·3	86·5	91·7	100	436
$(X, nX;\ YZ\colon S)$	3·6	5·8	12·9	17·8	20·0	26·2	32·9	43·1	50·2	100	225
$(X, X+1;\ X, X+1)$	46·6	59·3	67·9	70·6	74·2	80·1	81·4	87·8	91·8	100	221
$(X, X+1;\ YZ\colon S)$	2·4	6·2	8·6	10·9	12·9	19·0	23·3	38·1	51·4	100	210
$(X, X-1;\ X, X-1)$	36·9	46·2	57·8	60·4	64·4	70·7	76·0	83·6	91·1	100	225
$(X, X-1;\ YZ\colon S)$	1·9	3·3	7·1	10·4	11·9	16·6	19·4	31·3	46·4	100	211
$(XY;\ XY)$	36·4	48·6	61·0	67·2	72·0	73·3	82·8	89·0	95·0	100	418
$(XY;\ ZZ)$	0·0	0·5	1·4	2·4	2·4	4·7	7·6	18·7	31·6	100	212
$(XY;\ Z, nZ\colon S)$	0·9	1·4	4·6	5·1	5·5	11·0	17·0	33·9	49·1	100	218
$(XY;\ Z, Z+1\colon S)$	0·9	2·3	3·2	4·2	5·5	12·4	18·4	33·2	45·2	100	217
$(XY;\ Z, Z-1\colon S)$	0·5	1·5	2·9	4·4	5·8	12·1	18·8	30·0	42·5	100	207
$(XY;\ XZ\colon S)$	2·4	3·8	9·4	12·2	13·6	16·4	24·4	38·5	53·0	100	213
$(XY;\ ZY\colon S)$	2·4	4·7	10·9	13·2	15·6	21·7	28·3	40·1	54·2	100	212
$(XY;\ WZ\colon S)$	1·3	3·1	8·9	10·2	10·7	16·4	23·6	35·5	47·6	100	225
$(XY;\ WZ\colon D)$	0·5	1·8	7·6	10·3	13·1	18·0	24·3	38·3	51·8	100	222
$(XY;\ 0Z\colon S)$	3·1	4·4	6·2	8·4	10·2	15·5	21·2	28·8	41·6	100	226
$(XY;\ Z0\colon S)$	0·5	0·9	0·9	2·3	2·3	5·1	12·6	26·6	37·8	100	214
$(XY;\ 1Z\colon S)$	0·0	0·5	1·4	1·9	2·4	5·2	12·8	23·7	38·4	100	211
$(XY;\ Z1\colon S)$	0·0	0·0	1·9	2·8	2·8	7·5	14·6	27·2	41·3	100	213
$(0X;\ 0X)$	50·9	64·1	73·6	78·8	81·6	84·9	85·4	92·4	94·8	100	212
$(0X;\ YZ\colon S)$	0·0	0·0	0·5	0·5	0·9	3·7	11·7	24·3	37·8	100	214
$(X0;\ X0)$	52·5	69·5	76·2	80·3	81·6	83·9	85·2	90·1	93·7	100	223
$(X0;\ YZ\colon S)$	0·9	1·9	4·2	5·2	6·1	8·5	11·7	22·5	34·7	100	213
$(1X;\ 1X)$	47·6	56·1	64·6	70·7	73·1	75·5	79·2	83·9	89·6	100	212
$(1X;\ YZ\colon S)$	0·5	1·4	3·2	4·1	4·6	9·5	16·8	30·0	46·8	100	220
$(X1;\ X1)$	32·3	42·4	53·9	61·3	63·6	67·3	73·3	81·6	89·9	100	217
$(X1;\ YZ\colon S)$	0·5	1·9	6·2	9·1	10·5	15·2	20·0	33·3	46·7	100	210

rate in the conditions where the test pair and the presented pair have the same order than in the conditions where they have a different order, other things being equal. However, the effect is far from significant if χ^2 tests are used to compare 'yes' and 'no' responses in each condition, and there is a non-significant, opposite effect in some cases. By itself, numerical order is not an important cue in short-term recognition memory of digit pairs. This means either that numerical order is never an important cue or that it only contributes to the probability of recognizing a pair when there are other functioning cues. Some support for the latter alternative can be derived from the fact that the largest positive effects of numerical order were obtained in the conditions where the test pair had the highest degree of similarity to the presented pair (first or second digits identical).

Same versus different items and position. There are four pairs of conditions in Expt I [$(mX, nX; nX, mX)$ versus $(mX, nX; Y, Z)$, $(X, X+1; X+1, X)$ versus $(X, X+1; Y, Z)$, $(X, X-1; X-1, X)$ versus $(X, X-1{:}\ Y, Z)$, and $(XY; YX)$ versus $(XY; WZ{:}\ D)$] that were designed to determine whether the false recognition rate is higher for test pairs that consist of the same two digits as those in the presented pair, but in the wrong positions. Each of the four comparisons is in the direction of greater false recognition rate for pairs having the two presented digits in reverse positions than for pairs having no digits in common with the presented pair, and the overall comparison is significant ($\chi^2 = 5{\cdot}76$, D.F. 1, $P < 0{\cdot}02$).

Comparison of conditions $(XY; XZ{:}\ S)$, $(XY; XZ{:}\ D)$, $(XY; ZY{:}\ S)$, and $XY; ZY{:}\ D)$ with $(XY; WZ{:}\ S)$ and $(XY; WZ{:}\ D)$ in Expt I provides a test of the hypothesis that the false recognition rate is greater for test pairs having one digit in common with the presented pair in the same position than for pairs having nothing in common with the presented pair. The results support the hypothesis and the effect is significant ($\chi^2 = 7{\cdot}96$, D.F. 1, $P < 0{\cdot}01$). In addition, the effect on false recognition rate appears to be greater for the second item than for the first item of the pair. The analogous comparison of conditions $(XY; XZ{:}\ S)$, $(XY; ZY{:}\ S)$, and $(XY; WZ{:}\ S)$ in Expt II supports the same conclusions, but is not significant. The three comparisons of 'first items identical' with 'no common items' for *M*, *FO*, and *BO* presented pairs in Expt I are non-significant and inconsistent. However, for *NCR* pairs it is clear that false recognition rate is greater for test pairs with either the first or second item identical with the presented pair.

When the test pair and the presented pair contain one common digit, but in the wrong position, there is no significant effect on false recognition rate.

Nature of the digits (0, 1, 2–9)

There are three, theoretically distinct, ways of comparing recognition memory for pairs of the form *0X*, *X0*, *1X*, *X1*, and *XY*. One can compare false recognition rates for test pairs of the form *WZ* following each of the different types of presented pairs. One can compare false recognition rates for different types of test pairs following presented pairs of the form *WZ*. Finally, one can compare correct recognition rates for each of the pair types. If pairs with 0 and 1 in them are easier to remember, then it should be easier to reject incorrect test pairs of the form *WZ* when the presented pair had a 0 or 1 in it, and it should be easier to reject an incorrect test pair with a 0 or 1 in it after a presented pair of the form *WZ*. Finally, it should be easier to recognize the presented pair correctly.

In order to evaluate the strength of the memory trace for pairs of different types, it is necessary to be sure that the 'non-memory' response biases are the same for test pairs of different types. This is obviously no problem in the first of the above comparisons because all the test pairs are of the same type. However, in the last two comparisons, there may be some non-memory differences in the tendency to say 'yes' to test pairs of different types. The analogous problem occurs in signal detectability experiments, where the solution to the problem has been to compute the 'receiver operating characteristic' (ROC curve) for each condition. Applied to an experiment in recognition memory this function is more appropriately called the 'memory operating characteristic' (MOC curve). The MOC curve is a plot of $R_i(x)$, the 'correct recognition' rate for some condition x in which the probe pair is identical with the presented pair, against $R_i(y)$, the 'false recognition' rate for some control condition y in which the probe pair is of the same type as in condition x, but not identical with the presented pair. Since the MOC curve is a plot of two cumulative probability functions, one against the other, the curve originates at (0, 0) and ends at

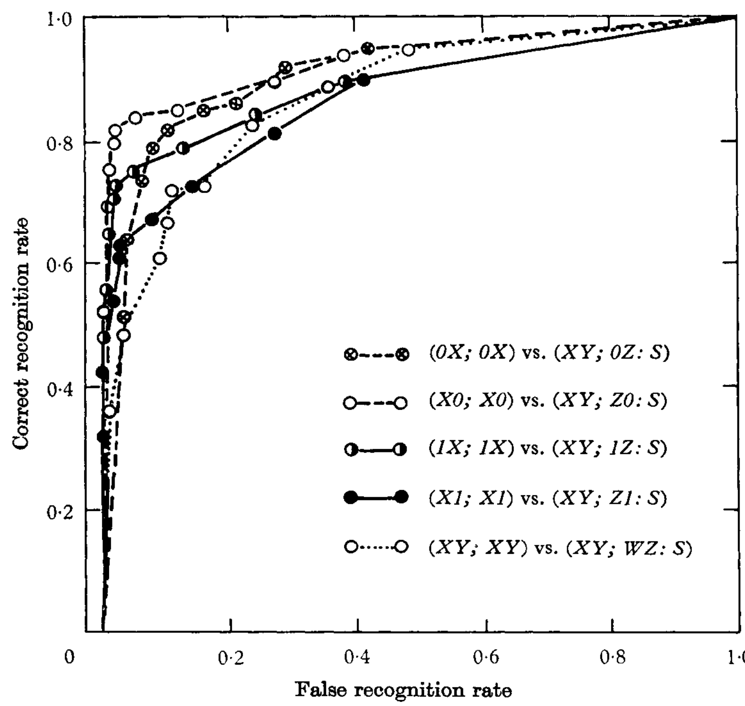

Fig. 1. 'Memory operating characteristic' (MOC) curves for *0X*, *X0*, *1X*, *X1*, and *XY* pairs in Expt. II.

(1, 1). If one type of digit pair is remembered better than another type of digit pair, then the MOC curve for the first type of digit pair will lie above the MOC curve for the second type of digit pair. This means that, for all values of the false recognition rate, the correct recognition rate for the first type of pair is greater than the correct recognition rate for the second type of pair.

False recognition rates for presented pairs containing 0 or 1. Conditions (*0X* ; *YZ*: *S*), (*X0*; *YZ*: *S*), (*1X*; *YZ*: *S*), (*X1*; *YZ*: *S*) and (*XY*; *WZ*: *S*) in Expt II have test pairs of the same type and differ only in the nature of the presented pair. Since (*XY*; *WZ*: *D*) does not differ from (*XY*; *WZ*: *S*), these two conditions are combined for all subsequent statistical analyses to increase the number of cases. False recognition rates for the above five types of presented pairs fall into three categories. Presented pairs beginning with zero (*0X*) produce a significantly lower false recognition rate than presented pairs ending with zero (*X0*) and beginning with one (*1X*), which in turn have a lower false recognition rate than pairs ending in one (*X1*) or having no zero or one (*XY*) ($\chi^2 = 6{\cdot}25$, D.F. 1, $P < 0{\cdot}02$ and $\chi^2 = 11{\cdot}12$, D.F. 1, $P < 0{\cdot}001$, respectively.

False recognition rates for test pairs containing 0 or 1. Conditions (*XY; 0Z: S*), (*XY; Z0: S*), (*XY; 1Z: S*), (*XY; Z1: S*) and (*XY; WZ: S*) in Expt II have presented pairs of the same type and differ only in the nature of the test pair. False recognition rates are substantially lower for test pairs containing a 0 or 1 ($\chi^2 = 23{\cdot}23$, D.F. 1, $P < 0{\cdot}001$), but test pairs of the form *0X* appear to have a higher false recognition rate than pairs of the form *X0*, *1X*, or *X1*.

Correct recognition rates for pairs containing 0 or 1. Comparison of the correct recognition rate in conditions (*0X; 0X*), (*X0; X0*), (*1X; 1X*), and (*X1; X1*) with (*XY; XY*) in Expt II is biased against the conditions with 0's or 1's in them because of their lower false recognition rate. In spite of this, a Kolmogorov–Smirnov test on the cumulative recognition functions shows that the correct recognition rate is higher in (*0X; 0X*), (*X0; X0*), and (*1X; 1X*) than in (*XY; XY*) [$D = 15{\cdot}6\%$, $P < 0{\cdot}01$; $D = 20{\cdot}9\%$, $P < 0{\cdot}001$; $D = 11{\cdot}3\%$, $P < 0{\cdot}06$, respectively]. The correct recognition rate in (*X1; X1*) is not significantly different from the rate in (*XY; XY*). The MOC curves for each of the five types of pairs is presented in Fig. 1. MOC curves control for differences in response biases by plotting correct recognition rate as a function of false recognition rate for each type of test pair, (*0X; 0X*) versus (*XY; 0Z: S*), (*X0; X0*) versus (*XY; Z0: S*), (*1X; 1X*) versus (*XY; 1X: S*), (*X1; X1*) versus (*XY; X1: S*), and (*XY; XY*) versus (*XY; WZ: S*). The MOC curves indicate that pairs with a zero in the first position, a zero in the second position, or a one in the first position are easier to remember than pairs with a one in the second position or pairs with no zero or one.

Nature of the relation between the digits (*I*, *M*, *FO*, *BO*, *NCR*)

False recognition rates for different types of presented pairs. Conditions (*XX; YZ*), (*X, nX; YZ: S*), (*X, X+1; YZ: S*), (*X, X−1; YZ: S*) and (*XY; WZ: S*) in Expt II have test pairs of the same type and differ only in the nature of the relationship of the digits in the presented pair. The false recognition rate is lower for *I* and higher for *M* presented pairs than for *NCR* presented pairs ($\chi^2 = 8{\cdot}99$, D.F. 1, $P < 0{\cdot}01$ and $\chi^2 = 7{\cdot}33$, D.F. 1, $P < 0{\cdot}01$, respectively). *FO* and *BO* presented pairs did not differ significantly from *NCR* presented pairs. The analogous comparisons in Expt II showed slightly lower false recognition rates for *I*, *M*, and *BO* pairs than for *NCR* and *FO* pairs, but no differences were significant.

False recognition rates for different types of test pairs. Conditions (*XY; ZZ*), (*XY; Z, nZ: S*), (*XY; Z, Z+1: S*), (*XY; Z, Z−1: S*), and (*XY; WZ: S*) in Expt II have the same type of presented pair and differ only in the nature of the relationship of the digits in the test pair. The false recognition rate is lower for *I*, *M*, *FO*, and *BO* test pairs than for *NCR* test pairs ($\chi^2 = 15{\cdot}00$, D.F. 1, $P < 0{\cdot}001$; $\chi^2 = 5{\cdot}98$, D.F. 1, $P < 0{\cdot}02$; $\chi^2 = 5{\cdot}92$, D.F. 1, $P < 0{\cdot}02$; $\chi^2 = 5{\cdot}15$, D.F. 1, $P < 0{\cdot}02$, respectively).

Correct recognition rates for I, M, FO, BO, and NCR pairs. Comparisons of the correct recognition rates in conditions (*XX; XX*), (*X, nX; X, nX*), (*X, X+1; X, X+1*) and (*X, X−1; X, X−1*) with (*XY; XY*) is biased against the *I*, *M*, *FO* and *BO* conditions because of their lower false recognition rate. In spite of this, a Kolmogorov–Smirnov test on the cumulative recognition functions shows that the correct recognition rate is significantly greater for *I* and *FO* pairs than *NCR* pairs ($D = 34\%$, $P < 0{\cdot}001$ and $D = 13{\cdot}2\%$, $P < 0{\cdot}02$, respectively). *M* and *BO* pairs are not significantly different from *NCR* pairs. The analogous comparisons in Expt I show a significantly higher correct recognition rate for *I* pairs than for *NCR* pairs ($D = 24{\cdot}2\%$, $P < 0{\cdot}001$) and no significant differences among *M*, *FO*, *BO*, *NCR* pairs.

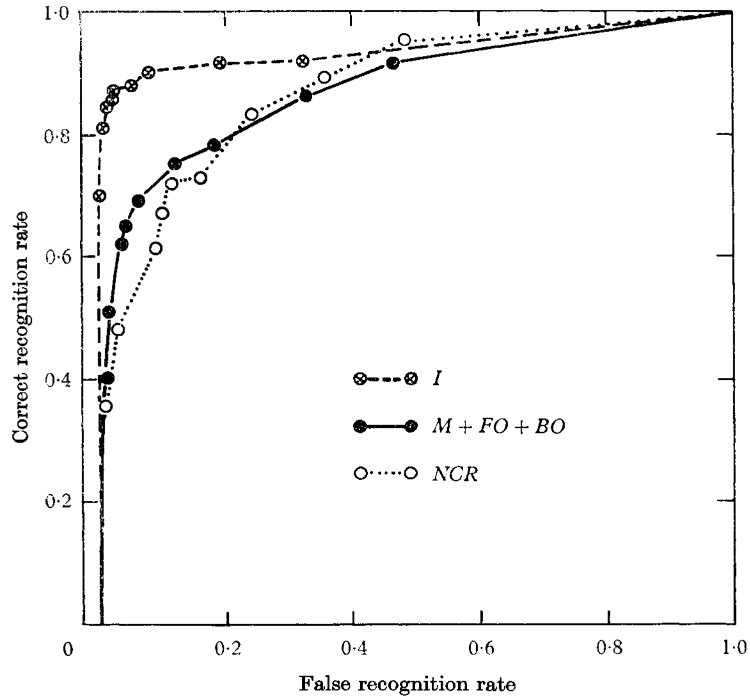

Fig. 2. 'Memory operating characteristic' (MOC) curves for *I*, *M*, *FO*, *BO*, and *NCR* pairs in Expt II.

The MOC curves for the pairs with different types of relationships between their digits are shown in Fig. 2. *M*, *FO*, and *BO* pairs have been averaged into one curve to make the figure clearer. Pairs consisting of two identical digits are remembered much better than the other types of pairs, and there appears to be some superiority for *M*, *FO*, and *BO* pairs over *NCR* pairs, but the latter difference is much smaller than the former.

Discussion

Unless one uses a paired associate procedure where every response item has its own special stimulus item, one experiences a peculiar kind of frustration in specifying the stimulus for recall of the first item of a serial list. The frustration is quite acute if there is only one item in the list, because then the problem is difficult to ignore. Within an associative theory of memory the solution to the problem may be as follows. Before and during presentation of an item, a well-instructed and well-motivated subject is thinking something like '—— is the presented item' and therefore, by simple contiguity, associations will be formed in both directions between the internal representative of the presented item and the internal representative of

'—— is the presented item'. At the time of recall a subject is able to activate the internal representative of '—— is the presented item'; and, if the association from '—— is the presented item' to the representative of the presented item is strong enough, then the presented item is recalled.

Recognition memory simply tests the strength of the reverse association, from the representative of the test item to the representative of '—— is the presented item'. If the association is strong enough to activate the representative of '—— is the presented item', then the subject says 'yes'. The exact nature of the internally generated concept, which has been symbolized by '—— is the presented item', is irrelevant to the present discussion. It makes no difference what the exact words are or even whether the concept is verbalizable at all. The conscious or unconscious nature of the concept activation process is also irrelevant, as are individual differences.

In the present study the presented 'item' is a pair of digits. During presentation of a pair, an association is formed between the representative of the presented pair and the representative of '—— is the presented pair'. When the test pair is identical to the presented pair, then the strength of this association is being tested. When the test pair is different from the presented pair, then what is being tested is the strength of the association between the representative of the test pair and the representative of '—— is the presented pair'.

If the internal representative of 74 has no more in common with the internal representatives of 47, 73, or 94 than it has in common with the internal representatives of 58, 92, 35, etc., then we should expect the false recognition rates to be identical for incorrect test pairs with different degrees of similarity to the presented pair. This is not the case. Test pairs with the higher degrees of 'identical elements' similarity (two identical digits in reversed positions or one identical item in the identical position) have significantly higher false recognition rates than test pairs with lower degrees of similarity. This suggests that the internal representative of 74 is composed of the sequential activation of the internal representatives of 7 and 4. The representative of 7 provides input to the representative of '—— is the presented pair'; the representative of '7 in the first position' provides even more input to the representative of '—— is the presented pair'.

The results of the present study clearly indicate that the probability of activating '—— is the presented pair' in response to the correct pair is not a simple multiplicative function of the probability of activating '—— is the presented pair' in response to each element of the pair. The evidence for this assertion is that the ratio $R_i(XY;\ XY)/R_i(XY;\ XZ:S)$ is much greater than the ratio $R_i(XY;\ XZ:S)/R_i(XY;\ WZ:S)$ for all values of i. Other ratio tests also fail to show the equality predicted by the simple multiplicative probability model. The failure of the simple multiplicative model does not imply that the representative of the whole is an indivisible unit, unrelated to the representatives of its parts. In fact, this latter hypothesis is rather unlikely in view of the relationship between similarity and false recognition. What seems to be indicated by the data is that the representative of each element of the pair provides input to the representative of '—— is the presented pair', but there is a non-linear relationship between the amount of input and the probability of activation. One such non-linear relation would be a threshold function.

The only type of similarity demonstrated to affect false recognition rate in the present experiments was identical elements similarity. The only type of relational similarity investigated in a systematic manner was the numerical order of the two digits in the pair, and numerical order had only a small and insignificant effect on false recognition rate. It seems likely that, if there is an effect of any type of relational similarity, it is small enough to require a much larger number of trials or subjects in order to demonstrate it than were used in the present experiments.

Pairs of the form *X1* appear to be remembered slightly better than pairs of the form *XY*; pairs of the form *0X*, *X0*, *1X*, and *XX* are remembered much better than *XY* pairs. Pairs with numerical relations more complex than identity (such as multiples, forward sequences, and backward sequences) are remembered a little better than *XY* pairs with no such numerical relations between their digits, but the difference is quite small. The present study was designed to demonstrate the existence of such differences and their approximate magnitude. Explanation of the differences seems difficult, but one can hazard the guess that subjects classify pairs into types. This means that a presented pair activates other concepts in associative memory that become associated to '—— is the presented pair' and thus provide additional cues for correct recognition. It seems likely that the defining concepts for 'special' pairs are simpler, for example, in number of 'words'. 'Ordinary' pairs are very likely defined negatively, that is, 'not two identical items', 'not containing a 0', etc. If there is only a limited amount of time for activating these defining concepts and, furthermore, no conscious intent to activate them, then the positive defining concepts of special pairs will be more likely to be activated during both presentation and test than the negative defining concepts of ordinary pairs. Thus, there will be better replication of the memory trace and the retrieval process for special pairs than for ordinary pairs. One could also argue that the number of pairs in any special class is smaller than the number of pairs in the ordinary class, which makes the defining concept a more valuable cue for special pairs than for ordinary pairs.

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