Reprinted from JOURNAL OF EXPERIMENTAL PSYCHOLOGY, Vol. 70, No. 1, July 1965
Printed in U. S. A.

ACOUSTIC SIMILARITY AND INTRUSION ERRORS IN SHORT-TERM MEMORY[1]

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36 undergraduates were given lists of 8 items (4 digits and 4 letters) presented at .75 sec/item with ordered recall instructions. Ss were either to copy the items as presented and then recall or to recall the items without prior copying. Recall after copying was slightly worse than recall without copying ($p < .05$). In both conditions, intrusions among letters and between letters and numbers tended to follow acoustic similarity ($p < .001$). Vowel similarities were more important than consonant similarities, but both effects were significant ($p < .001$). There was a correlation of .58 between the number of letters similar to a presented letter and the frequency with which that letter was forgotten ($p < .01$). Short-term memory appears to use an auditory or speech-motor code.

Conrad (1962, 1964) investigated intrusion errors in the immediate recall of lists of six letters drawn from the following 10 letters: B C P T V, F M N S X. He found that letters whose pronunciation ends with an "ē" sound (B C P T V) tend to be confused with each other in recall and letters whose pronunciation begins with an "ĕ" sound (F M N S X) tend to be confused with each other in recall. This was true even though the letters were presented *visually* at the rate of .75 sec/letter under conditions where the probability of perceptual error was known to be negligible.

It is tempting to draw three conclusions from Conrad's study: (*a*) Short-term storage is auditory (or speech-motor). (*b*) Acoustically similar items are represented by similar traces (either overlapping sets of neurons or similar patterns of firing of neurons). (*c*) Partial forgetting of an item is possible, producing intrusion errors that share the unforgotten property common to both the original item and the intrusion.

[1] This investigation was supported by Grant MH 07726-01 from the National Institute of Mental Health, Public Health Service.

The present study attempts to provide further support for these conclusions by investigating intrusions involving all 26 letters and the digits 1 through 9. If the above conclusions are valid, there should be a significant tendency for confusions among letters and between letters and digits based on *any* vowel or consonant acoustic similarity. In addition to the ē and ĕ sounds common to many letters and digits, there are other vowel sounds (ā, ū, ī, ō) and consonant sounds (/k/, /s/, /j/, etc.) common to two or more letters or digits. If Conclusion *c* is valid, the frequency of letter intrusions for any letter should correlate with the number of letters which share a sound in common with the presented letter. Similarly, the number of digit intrusions for any letter and the number of letter intrusions for any digit should correlate with the number of digits or letters, respectively, with which a common sound is shared.

The present study differed in several ways from Conrad's experiment, which should test the generality of the relationship between acoustic similarity and intrusions in short-term recall. First, presentation of the items was auditory rather than visual. Perceptual errors were excluded by having *S*s copy the list as it was presented, cover what they had written, and then recall the list. Only items that were perceived correctly were scored for correct or incorrect recall. Second, lists contained eight items, rather than six items, because the memory span of our *S*s was much greater. Third, lists contained both letters and digits, not just 10 selected letters as in Conrad's experiment.

METHOD

Lists of eight different items, four letters and four digits in random order, were presented on tape at the rate of .75 sec/item. The letters were drawn randomly from the set of all 26 letters, and the digits were drawn randomly from the set 1 through 9. There were two conditions in the experiment: (*a*) Recall and (*b*) Copy + Recall. In the *recall* condition *S*s were instructed to attempt to fill in eight boxes with the correct list of eight items in the correct order, beginning their recall after the entire list of eight items had been presented. In the *copy + recall* condition *S*s were instructed to copy the eight items while they were being presented, and as soon as they had finished copying they were to cover what they had written and attempt to recall the list, as in the *recall* condition. Each *S* received 50 lists under each condition. Thirty-six Massachusetts Institute of Technology undergraduates taking psychology courses participated in the experiment, half receiving the two conditions in one order and half in the other order.

RESULTS

Conrad scored only lists in which there was one and only one error. In the following analysis this criterion was relaxed to include all extralist intrusions where the correct item was not recalled at some other position in the list and those intralist intrusions which occurred in lists with only one error. The presumed purpose for Conrad's selection method and the explicit purpose of the present selection method is to eliminate cases where the intrusion error may be presumed to result from forgetting the exact *position* of an item, rather than partial or complete forgetting of the *item*.

In order to eliminate perceptual errors, the following analysis is limited to those cases where an *S* copied an item correctly and then failed to recall the item correctly. Virtually all of the mistakes in copying (68 out of 84) involved substitution of an acoustically similar item for the presented item, where "acoustic similarity" means "possessing some sound in common." In 70 out of the 84 cases of copying error, there was only one copying error in the list. Substitutions of letters for letters accounted for 58 copying errors; substitutions of numbers for letters accounted for 16 copying errors; substitutions of letters for numbers accounted for 3 copying errors; substitutions of numbers for numbers accounted for 7 copying errors.

Intrusions of Letters for Letters

Table 1 presents the vowel and consonant sounds that occur in two or more English letters. In addition, Table 1 reports the frequency with which letters possessing a common sound are substituted for each other as intrusions in recall after correct copying. Both the vowel and consonant totals are individually significant at far beyond the .001 level in demonstrating a higher frequency of same-sound intrusion errors than would be expected by chance. The vowel sounds have a higher relative frequency of same-sound intrusions to different-sound intrusions than the consonant sounds, but both effects are very significant. The only lingering doubt about the generalization that letter intrusions tend to be acoustically similar to the presented letter is in the case of the consonant similarity classes: B W, L W, D W, and K Q X. The first three classes involve letters which are extremely different in temporal and phonemic length, and the first two classes involve letters in which the common phoneme occupies a very different position in the sequence of phonemes. As an example of both these differences consider B (/biy/) and W (/dubilyuw/). B is two phonemes long, and W is seven phonemes long.[2] /b/ is at the beginning of /biy/, and in the middle of /dubilyuw/.

K (/key/), Q (/kyuw/), and X (/eks/) show no examples of same-sound intrusions out of 13 total intrusions. Each pair of letters possessing the /k/ phoneme does differ in either phonemic length or position of the /k/ phoneme in the sequence of phonemes comprising the pronunciation of the letter. However, the differences are not very large, and differences of this magnitude did not seem to eliminate the greater frequency of same-sound intrusions in letters containing common vowel sounds. The most reasonable explanation for the greater effects obtained with /j/ and /s/ than with /k/ is that the temporal duration of /k/ in pronunciation is much less than the durations of /j/ and /s/ (.08 sec. vs. .18 sec. and .23 sec.—Fletcher, 1953, pp. 62–66). Duration also explains the greater effects with vowels than with consonants. Fletcher (1953) obtained durations of .34 sec. for ē, .30 sec. for ā, and .22 sec. for ĕ, which are much longer than the duration of the average consonant. The differences *among* these vowels in degree of relationship between acoustic similarity and intrusion errors also fit this pattern. Fletcher gives no data on ī and ū, but one suspects they are longer than ĕ, which is *contrary* to the simple hypothesis that the degree of relationship between acoustic similarity and intrusions is dependent on duration of the common sound. The difference between /s/ and /j/ is also contrary to this hypothesis. It is likely that other factors, such as differences in temporal or phonemic length and position of the common sound in the letters possessing a common sound, are also important determinants of the degree of relationship between acoustic similarity and intrusions. We can conclude that acoustic similarity is related to intrusions of letters for letters, but we cannot draw any definite conclusions about the factors that affect the degree of this relationship.

Each of the 26 letters was ranked according to two criteria: (*a*) the total number of letters possessing some sound in common with it and (*b*) the frequency of *all* intrusions for the given letter. The Spearman rank-order correlation between these variables was .70, $t\ (24) = 4.8$, $p < .001$, two-tailed. This correlation is composed of: (*a*) a correlation of .14 (*ns*) between the number of letters similar to a given letter and the frequency of similar intrusions per similar letter and (*b*) a correlation of .38, $t\ (24) = 2.0$, $p = .06$, two-tailed, between the number of letters similar to a given letter and the frequency of dissimilar intrusions per dissimilar letter. The correlation between the number of letters similar to a given letter and the frequency of forgetting the letter was .58, $t\ (24) = 3.48$, $p < .01$, two-tailed. The frequency of forgetting a letter includes omissions as well as all intrusions. It has already been established that when a letter is not correctly recalled, the intrusions substituted for the letter tend to be acoustically similar to the presented letter. The correlations ob-

[2] We shall consider syllabic nuclei, such as /iy/ and /uw/ to be single phonemes.

TABLE 1

FREQUENCY OF SAME-SOUND AND DIFFERENT-SOUND INTRUSIONS OF LETTERS FOR LETTERS IN RECALL AFTER CORRECT COPYING

Sound	Letters Containing Sound	Same-Sound Intrusions	Different-Sound Intrusions	p
ā = /ey/	A H J K	9	7	.001[a]
ē = /iy/	B C D E G P T V Z	52	29	.001[a]
ĕ = /e/	F L M N S X	14	16	.001[a]
ī = /ay/	I Y	2	7	.05[b]
ū = /yuw/	Q U W	4	8	.001[a]
Vowel total		81	67	.001[a]
/b/	B W	0	10	
/d/	D W	1	10	
/k/	K Q X	0	13	
/l/	L W	1	10	
/s/	C S X	6	15	.01[a]
/j/	G J	8	8	.001[a]
Consonant total		16	66	.001[a]
Total		97	133	.001[a]

Note.—p = probability of obtaining this frequency of same-sound intrusions by chance (χ^2 for large n, binomia test for small n).
/ / indicates the phonemic representation of the sound.
[a] Two-tailed.
[b] One-tailed.

tained here show that the probability of forgetting a letter and making an intrusion error, either similar or dissimilar, is greater for letters with many similar letters than for letters with few similar letters. A letter that shares a common sound with many other letters is more likely to be forgotten than a letter that shares a common sound with few other letters.

Intrusions between Letters and Digits

The findings for intrusions of letters for digits were identical in all respects to the findings for intrusions of digits for letters. Hence, the data are combined in the following analyses. Table 2 presents four categories of intrusions between letters and digits and the frequency of intrusions in each category. The four categories are: (*a*) Confusions involving a letter which possesses a sound in common with the digit and which is in the spelling of the digit, (*b*) Confusions involving a letter which possesses a sound in common with the digit but which is not in the spelling of the digit, (*c*) Confusions involving a letter which has no sound in common with the digit but which is in the spelling of the digit, and (*d*) Confusions involving a letter which has no sound in common with the digit and which is not in the spelling of the digit. The findings in Table 2 are for intrusions occurring in recall after correct copying, just as in Table 1.

The results are clear. Intrusions between letters and digits tend to be acoustically similar, just as intrusions of letters for letters. Intrusions involving items from two different conceptual categories, letters and digits, tend to follow acoustic similarity just as do intrusions involving items from the same category. The analysis of "silent letters" (letters in the spelling of a digit that are not in the pronunciation of the digit) and the analysis of "invisible sounds" (letters not in the spelling of the digit, but possessing a common sound) suggest that it is the sequence of sounds, rather

TABLE 2

Frequency of Same-Sound and Different-Sound Intrusions between Letters and Digits in Recall after Correct Copying

Digit	Letters with Same Sound, in Spelling	Letters with Same Sound, Not in Spelling	Letters with Different Sound, in Spelling	Letters with Different Sound, Not in Spelling
1	(N) 1	(Y) 0	(OE) 1	25
2	(TW) 1	(UQ) 4	(O) 2	12
3	(RE) 5	(BCDGPTVZ) 17	(H) 0	4
4	(FOR) 9		(U) 0	8
5	(FIV) 6	(Y) 4	(E) 1	10
6	(SX) 4	(CK) 3	(I) 0	7
7	(SVN) 3	(CXFLM) 8	(E) 0	15
8	(HT) 4	(AJK) 7	(EIG) 8	19
9	(NI) 5	(Y) 3	(E) 0	10
Total observed f	38	46	12	110
Expected f	17.6	20.2	10.6	157.6
p	.001	.001	*ns*	

Note.—p denotes the significance level in a 2 × 2 χ^2 table comparing the frequency of each column with the frequency in the last column.

than the sequence of letters, which is encoded in short-term memory.

The Spearman rank-order correlation between the number of letters acoustically similar to a given digit and the total frequency of intrusions between letters and digits involving that digit was .30, t (7) = 0.84, *ns*. The correlation between the number of letters acoustically similar to a given digit and the total frequency of forgetting the digit was .44, t (7) = 1.29, *ns*. Again the results are the same as for intrusions involving only letters, though not significant because the number of degrees of freedom is smaller.

Intrusions of Digits for Digits

The present experiment confirmed a finding by Conrad (1959) that there are no systematic confusions between digits in short-term recall. This is in perfect agreement with the hypothesis that intrusions follow acoustic similarity since every digit is acoustically very different from every other digit. There are fewer acoustic similarities and more differences among digits than among letters or between digits and letters.

Comparison of Recall after Copying with Recall

The data were analyzed for ordered recall, item recall, and position recall for items. The *S*'s report of an item is correct by an ordered recall criterion if and only if the correct item is recalled in the correct position. The *S*'s report of an item is correct by an item-recall criterion if and only if it appears anywhere in his report of the list in question. Position recall, independent of item recall, is obtained by subtracting the item-recall errors from the ordered-recall errors, reducing the total number of possible errors by the same amount when computing the error rate for position recall.

When the two conditions are compared by any of the three measures of recall, the number of errors in each condition for each *S* is counted and one is subtracted from the other to give a difference score favoring one condition or the other. Superiority of one condition over the other is determined by applying the Wilcoxon matched-pairs signed-ranks test to the 36 difference scores.

Recall after copying is worse than

TABLE 3

COMPARISON OF RECALL WITH RECALL AFTER COPYING: NUMBER OF INTRUSIONS

	Intrusions among Letters		Intrusions between Letters and Digits			
	Similar	Dissimilar	Same Sound, in Spelling	Same Sound, Not in Spelling	Different Sound, in Spelling	Different Sound, Not in Spelling
Recall	98	61	51	54	13	109
Recall minus estimate of copying errors	45	56	43	52	13	100
Recall after copying	92	62	38	46	12	110

Note.—The figures for intrusions among letters in recall after copying in Table 3 are less than the totals in Table 1 because an intrusion may be similar or dissimilar in more than one respect. In Table 1, one intrusion was often counted twice. In Table 3, each intrusion was classified as similar in any respect or dissimilar, and so was counted only once. Expected values were computed differently in the two cases.

recall without prior copying in ordered recall, item recall, and position recall ($p < .05$, two-tailed test, $n = 36$, in all three analyses). The differences are not large, but they are in the expected direction. It is not surprising that copying during presentation reduces the memory span since writing is certainly slower than silent rehearsal and must take some time away from silent rehearsal. What is surprising is that the difference is so small. Even though it is slower than silent rehearsal, writing the items in order may be a particularly useful type of rehearsal when recall also consists of writing the items in order. But regardless of the reason, immediate recall of familiar letters and digits presented at .75 sec/item is not much worse when the items are copied than when the items are not required to be copied during presentation.

The central issue in this comparison of recall with recall after copying is whether the relationship between acoustic similarity and intrusions is any different in the two conditions. Table 3 summarizes the totals for similar and dissimilar intrusions among letters and between letters and digits for recall and recall after copying. Since the totals for recall include some perceptual errors as well as recall errors, the copying errors in the recall-after-copying condition have been taken as an estimate of perceptual errors in the recall condition and subtracted from the totals for the recall condition in the second line of Table 3. This adjustment has little effect on the totals for intrusions between letters and digits, but reduces the frequency of similar recall intrusions among letters by half. However, the relationship between acoustic similarity and intrusions is still significant at beyond the .001 level both among letters and between letters and digits. The relationship may be a little weaker when recall is not preceded by copying, but there is no way to be sure of this since we cannot check the assumption that copying errors provide an estimate of the perceptual error rate when the items need not be copied. One can imagine the estimate might be in error in either direction. It is for this reason that primary emphasis was placed on the analysis of recall intrusions that followed correct copying. Only in recall after correct copying can perceptual errors be eliminated from the recall data.

DISCUSSION

The findings of the present experiment are in complete agreement with the findings of Conrad (1962, 1964) and support the three conclusions mentioned in the introduction: (*a*) Short-term storage uses an auditory (or speech-motor) code. (*b*) Acoustically similar items are represented by similar traces. (*c*) Partial forgetting of an item is possible, producing intrusion errors that share the unforgotten property common to both the original item and the intrusion.

There is a one-to-one correspondence between every sound mentioned in this article and a speech-motor response that produces that sound. Therefore, the present findings imply nothing about the sensory vs. motor nature of the short-term memory trace. Also, these findings do not rule out the possibility that visual-sensory or writing-motor systems play some role in short-term memory. What the present findings do imply is that short-term memory uses either an auditory or a speech-motor code for at least *part* of the trace. No evidence available at present requires one to postulate any replication of short-term traces outside of the auditory or speech-motor systems, and any such replication of the trace using a code not isomorphic to an auditory code would have had a tendency to prevent results such as those obtained in the present experiment. Nevertheless, we cannot be positive that these short-term traces use *only* an auditory or speech-motor code. Incidentally, *very* short-term memory for brief simultaneous visual displays (Sperling, 1960) very likely uses a visual code and is beyond the scope of this article.

According to the auditory or speech-motor theory of short-term memory, the letter J is composed of the consonant /j/ and the vowel /ā/. When J is presented, the internal representatives of both /j/ and /ā/ are activated. When /j/ and /ā/ are activated, J is recalled. When only /j/ is activated, either G or J may be recalled. When only /ā/ is activated, A, H, J, or K may be recalled. When neither /j/ nor /ā/ is activated, any intrusion is equally probable and there may be many omissions. Without the assumption that partial recall of a letter or digit is possible, it seems difficult to account for the present findings.

With the partial-recall assumption, it follows that the greater the number of items sharing a common property with a given item, the greater the probability of making an error when the item is only partially recalled. For example, if one remembers that a letter had an /ā/ in it, one has a .75 chance of guessing incorrectly; if one remembers that a letter had an /ē/ in it, one has a .89 chance of guessing incorrectly. Therefore, /ā/ letters should be "forgotten" less often than /ē/ letters, but the effect should be entirely reflected in an increased probability of making a *similar* intrusion error. The present experiment demonstrated increases in the frequency of *both* similar and dissimilar intrusion errors. In fact, the effect for dissimilar intrusions was larger than the effect for similar intrusions. This result suggests that items with more similar items are more likely to be wholly or partially *forgotten* than are items with fewer similar items.

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(Received April 18, 1964)