THE AMERICAN
JOURNAL OF PSYCHOLOGY
Founded in 1887 by G. STANLEY HALL

Vol. LVI JULY, 1943 No. 3

THE LEARNING OF RADIOTELEGRAPHIC CODE

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In all languages employing a Latin alphabet, radiotelcgraphic communication is carried on through the use of the International Morse Code, also known as the Continental Code. For other languages, such as Japanese and Egyptian, special codes have been developed. They will not, however, concern us here.

The International Morse Code is composed of two kinds of elements, ordinarily called *dots* and *dashes.* Each letter of the alphabet, each numeral, and each punctuation mark is represented by a particular combination of dots and dashes. A dot is a tone of a constant frequency (usually between 500 and 1,000 c.p.s.) which lasts for a certain length of time. Similarly, a dash is a tone of the same frequency but of longer duration.

The absolute duration of a dot, a dash, or an intervening space ordinarily varies as a function of the speed of transmission. By international agreement, however, the dots, dashes, and spaces at any given speed have the following relative durations: a dot is defined as a unit, a dash is three units, a space within a character is one unit, a space between two characters is three units, and a space between two words is five units. (The U. S. Army and Navy have adopted the use of an inter-word space equal to seven units instead of five.)

Proficiency in the use of the code is ordinarily described in terms of the number of words per min. that an operator can transmit or receive. By definition a word is composed of five characters. Thus, to compute the speed of transmission of a particular message, one merely counts the

* Accepted *for* publication March I, 1943. The research described in this paper was previously reported in a dissertation submitted to the Graduate School of Arts and Sciences of Harvard University, March 18, 1943, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The writer wishes to express his appreciation to Professor Edwin G. Boring who acted as consultant during the execution of the experimental investigation and the preparation of the present paper.

number of characters sent in one minute and then divides this number by five.

The range of proficiency attained in the use of the International Morse Code is wide. It varies from the amateur standard of transmission and reception of meaningful material at 13 words per min. to the highest speed of reception on record, 75.2 words per min. The minimal requirement for a first-class commercial license is the transmission and reception of meaningful material at 23 words per min, and of nonsense material at 20 words per min. (Nonsense material consists of groups of characters which do not form words in any language and which are usually unpronounceable.)

The outbreak of the present war and particularly the entrance of the United States into the conflict resulted in an enormous increase in the demand for men proficient in the use of the International Morse Code. Not only was the existing supply of operators inadequate, but also the facilities of the existing training schools were just sufficient to train a small proportion of the total number of operators needed. To meet the demand, a large number of new schools were established. The actual number of operators now being trained is of course not public information. A conservative estimate, however, would indicate that more than 10,000 men are being graduated from schools of radiotelegraphy each month.

The necessity of training a very large number of men in the shortest possible time has brought to attention two groups of problems of immediate practical importance. Before the war, from eight to ten months were ordinarily required to train an operator. In peace-time this period might not be considered unnecessarily long. In time of war, however, it becomes urgent that the training period be shortened as much as possible. To accomplish this end, the most efficient procedures for teaching men to receive and to send code must be determined.

The second group of problems involves the selection of men for training in code. Individuals vary greatly in their ability to learn the code. Many do not possess the necessary aptitude. Of the men entering schools of radiotelegraphy from 30 to 60 per cent fail to become proficient operators. This, of course, means an enormous waste of instructional facilities and of the time of the men who fail. The development of an adequate method for the selection of personnel is of immediate importance.

The present study was undertaken in an attempt to make some contribution to the solution of these two groups of problems. Actually it was found that the first group was divisible into two separate and relatively independent parts, the problems involved in learning to receive and those

concerned with learning to send. Accordingly, the discussion which follows will be divided into three parts: (I) Learning to receive, (II) Learning to send, and (III) Measurement of aptitude.

I. Learning to Receive

1. *Experimental Procedure.* The number of factors affecting the speed with which a student learns to receive code is much larger than a survey[1] of previous studies might lead one to believe. Indeed, although other factors have been mentioned in such studies, attention has been primarily given to but one, the speed of transmission of individual characters during learning.

In order to determine the optimal conditions and procedures for instruction in receiving, it would be desirable to investigate experimentally each of the important parameters of learning to receive. Unfortunately, however, the fact that the study of a single parameter requires that a group of men be taught daily over a period of two months or longer, made such a systematic investigation of more than a few parameters practically impossible.

In the present investigation, therefore, it was necessary to select for study only those variables which seemed of most importance and of most interest at the present time. On this basis three problems were chosen. The problems actually selected, together with the reasons for their selection, will be presented in turn as the individual experiments are discussed.

In carrying out these three experiments, four groups or classes of men were given instruction in the use of the code. Classes A and B met during the Summer School of 1942 and Classes C and D during the Fall Term of the same year. Enrollment in the classes was open free of charge to Harvard students who wished to learn the code in anticipation of future military service. At that time certain branches of the armed forces offered special opportunities to men with two years of college and a Class B Amateur License. Accordingly, the immediate goal of most of the men enrolling was the attainment of a sending and receiving speed of 13 words per min., the degree of proficiency required for this license. There were 13 men in Class A, 13 in Class B, 15 in Class C, and 17 in Class D.

Since all four classes were drawn from the same population, it would be expected that they would be relatively homogeneous in their composition. The results of tests given in the course of experimentation indicate that

[1] For a review of all the previously-published studies relevant to the learning of code sec D. W. Taylor, Learning telegraphic code, *Psychol. Bull.,* 40, 1943, 461-487.

this was the case. The men were all of about the same age. In addition, the four classes were about equal in general intelligence, the mean scores attained on the Revised Alpha Examination Form 7 being 175, 178, 178, and 177, respectively. More important than this, however, is the fact that the classes were, insofar as one can tell, well-matched in their aptitude for learning code. The mean scores attained by the four classes on the Signal Corps Code Aptitude Test were 58, 60, 58, and 58, respectively. On the Initial Learning Test, which proved to provide an even better indication of code aptitude, the mean scores were 67, 66, 74, and 68. These results indicate that, had the four classes been subjected to the same experimental procedure, equivalent results would have been attained.

Since there is a relatively large number of factors which, it appears likely, affect the speed with which students learn to receive, it was of course necessary in carrying out the present experiments to control such factors. Accordingly, the conditions and procedures used in teaching the control class, Class A, were the same as those used in teaching the experimental classes, B**,** C, and D**,** with the exception in each case of the variable being studied.

First of all, the same classroom and apparatus were used in the instruction of all four classes. Each man was supplied with a desk, an ordinary telegraph key, and a pair of Type-A Brush Communication Phones. The telegraph key and the headphones were connected in series with each other and with a switchboard on the instructor's desk in the front of the room.

In addition to the switchboard, the instructor’s desk was equipped with a beat-frequency oscillator which was used to supply a tone of constant frequency. For the first 23 hours of practice in all classes, a tone of 1900 c.p.s. was used. Because of the fact that in actual practice tones of different frequencies are employed, it was desired to give the students practice in receiving other frequencies. Hence the frequency of the transmission tone was reduced to 1000 c.p.s. at the end of the first 23 hours of practice in all classes and maintained at this frequency until the end of learning.

For the instructor’s use in sending during receiving practice both an ordinary telegraph key and a McElroy semi-automatic key were provided. A microphone and amplifier were so arranged that it was possible for the instructor to speak directly to all students through the interphone system. Finally, the output of a record-player was connected to the input of the amplifier, thus making it possible to use the interphone system in giving recorded tests.

With the writer as instructor, each class met one hour a day, five days a week, Monday-Friday, for a total of 40 hours. In teaching, hand-sending, either with an ordinary or with a semi-automatic key, was used exclusively in all four classes. Although the classes were nominally one hour in length, the actual working time was about 50 min. Two or three rest-periods of about two min. in length were given daily in each class.

During the first twelve hours, the entire period each day was devoted to practice

in *receiving*. Sending practice was initiated on the 13th day and was given regularly thereafter on about every second day. A total of about 7 hours out of the 40 hours was devoted to practice in sending. Thus, the actual time spent in learning to receive was about 33 hours.

Of the 60 or more characters represented in the International Morse Code, 40 were selected to be taught to each of the classes. These 40 included the 26 letters of the alphabet, the 10 numerals, and four punctuation marks (period, comma, question mark, and fraction bar). These are the ones most frequently used and the ones usually taught in schools of telegraphy. The other characters are ordinarily learned only incidentally after the student has become proficient in telegraphy.

In all of the classes the students were instructed to attempt to learn to recognize the individual characters as organized auditory patterns and to avoid analyzing them into their component dots and dashes. Because their use fosters the tendency to analyze the characters, visual symbols were never presented in class. For the same reason the instructor carefully avoided referring to individual characters in terms of their component dots and dashes. Likewise, all mnemonic devices, such as "*I* is two dots because you have two eyes," were avoided.

In all four classes both nonsense and meaningful materials were used for practice. For various reasons[2] it has frequently been recommended that instructors transmit nonsense rather than meaningful material in teaching students to receive. There is, however, no adequate experimental evidence to show that such a procedure is actually better. The one marked advantage which meaningful material possesses over nonsense material is that it is more interesting to the students. It was primarily for this reason that, although practice was given regularly with nonsense material, meaningful material was predominantly used.

At the beginning of the third hour of practice in each class, a simple test was given to determine what proportion each student had mastered of the characters presented up to that time. The test consisted of 26 items, each of the characters learned during the first two hours of practice being included twice, The characters were transmitted in random order. Each was sent once and followed by a 5-sec, pause. During this pause each student wrote down on his test sheet the symbol for the character sent. Each man received as his score the number of characters which he identified correctly.

In like manner, similar tests were given at the beginning of the fourth, fifth, sixth, and seventh hours of practice, the number of items included in each being 36, 48, 64, and 80, respectively. These tests provided a measure of the speed with which the individual students initially learned the characters.

By the end of the 7th hour of practice most of the men could identify nearly all of the 40 characters correctly. Accordingly, to measure each student's progress from this point, speed-tests were given regularly every second hour from the 8th to the 22nd hours. From the 23rd to the 40th hour, speed-tests were given on the average of about once for every 2.5 hours of practice.

Each speed-test consisted of a number of meaningful messages, each 1-min. in length, alternated with a number of nonsense messages of the same length. Each successive meaningful and each successive nonsense message contained an average of 2.5 characters more than the message of the same kind preceding it. Thus, since

[2] For a summary of such reasons see Taylor, *op. tit.*

all messages were about l-min. long, the speed of transmission of successive meaningful and of successive nonsense messages increased by half-word steps. The minimal speed of transmission used in speed-tests was three-words-per-min.

The meaningful messages in the speed-tests were obtained by selecting at random sentences of appropriate length from the *Readers Digest.* The nonsense messages contained an equal frequency of all of the 40 characters and were composed of groups varying in length from two to eight characters.

The speed-test was presented in the following manner. The instructor transmitted the one-minute messages one at a time. After a 15-sec. pause following each message, he read the message which had just been sent. Each student checked his own paper. Only messages in which all the characters had been received perfectly were counted as correct.

Meaningful and nonsense messages were transmitted alternately as the speed of sending was increased in half-word steps. (In the speed-tests given during the last few hours of practice, the rate of sending was increased in one-word rather than half-word steps.) When the rate of sending reached the point at which no student in the class received a particular nonsense message correctly, no more of these messages were sent. Similarly, when the rate of sending reached the point where no student in the class received 2 particular meaningful message correctly, the test was considered to have been completed.

Each student was given two scores. The first represented the highest speed at which he had received a meaningful message perfectly; the second the highest rate at which he had received a nonsense message correctly.

The practice of allowing the student to check his own paper is open to criticism. Indeed it is a procedure that probably could not be used successfully in many schools in radiotelegraphy. The writer believes, however, that its use with the present classes produced valid results.

The student understood that his scores were being obtained for research purposes and that because of this fact they must be accurate. Nearly every student seemed to feel that he was indebted to the instructor for providing instruction in the code free of charge. For this and other reasons, excellent cooperation was obtained from all of the classes. Because of such cooperation, it seems probable that the scores obtained in the manner described were more accurate than they would have been had the instructor attempted to check all of the papers himself. An individual student would he more likely to note one error which he had made in a particular message than would an instructor who had to check on the average a thousand or more messages every day a speed-test was given.

Students were kept informed of their progress from day to day by means of individual progress-charts placed on a large bulletin board in the rear of the classroom. Each student’s speed of receiving meaningful material and his speed of receiving nonsense material were plotted as a function of the number of hours of practice. Such speeds were expressed in terms of characters per min, rather than words per min, in order to emphasize relatively small amounts of progress. Although the student's graph was identified only with his initials, the men soon learned to identify the charts of all those in their own class.

The use of the individual progress-charts motivated the men in two ways. First, every student endeavored to make on each successive speed-test a better score

than on the preceding. Secondly, in all classes friendly rivalry arose among men attaining about the same degree of proficiency.

2. *Order of Initial Learning of the Characters.* The first problem selected for investigation was the determination of the relative efficiency of two different orders of learning the characters.

Because it is not practical for a student to learn the 40 characters at once, a certain number must be presented each day until all have been learned. A common procedure is to divide the characters into groups which are similar in pattern and then to learn one group each day. Thus *E* (.), *I* (..), S (...), H (....) and *5* (.....) would be learned one day,

and the next day T (—), *M* (— —), *O* (— — —), and *zero* (— — — — — —).

With one change, this plan was used in teaching the control class, Class A (and also Classes C and D). This one change was made because in each of the four classes an aptitude test was given during the first learning period. As a part of the aptitude test, the students were taught eight characters not necessarily similar

TABLE I

ORDERS OP INITIAL LEARNING OP THE CHARACTER®

Class A and Class B both learned the first 8 characters in taking an aptitude test, the Initial Learning Test, during the first hour of practice. After the first hour, however, similar characters were taught together in Class A and dissimilar characters in Class B.

Hour of Practice	Class A: Similar	Class B: Dissimilar
1	. , / ? 2 9 F C	. , / ? 2 9 F C
2	E I S H 5	E M H P X
3	T M O 0 1	8 A G 7 K
4	A U V 4 R L	T B 3 J I N
5	N D B 6 J G P	R D Q V O U L S
6	Z K X Y Q 7 8 3	5 W Y 1 Z 0 4 6

in pattern. On the succeeding days, however, the characters were presented in similar groups.

Recently, however, the practice of teaching similar characters together was criticized by a member[3] of the American Communications Association. Characters which are most similar are those which are most difficult to discriminate. Therefore, he contended, teaching similar characters together makes the first stages in learning unduly difficult and confuses the student. He recommended that those characters which are most dissimilar be taught together, to permit the student to learn relatively easy discriminations at first and gradually to increase the difficulty of discrimination.

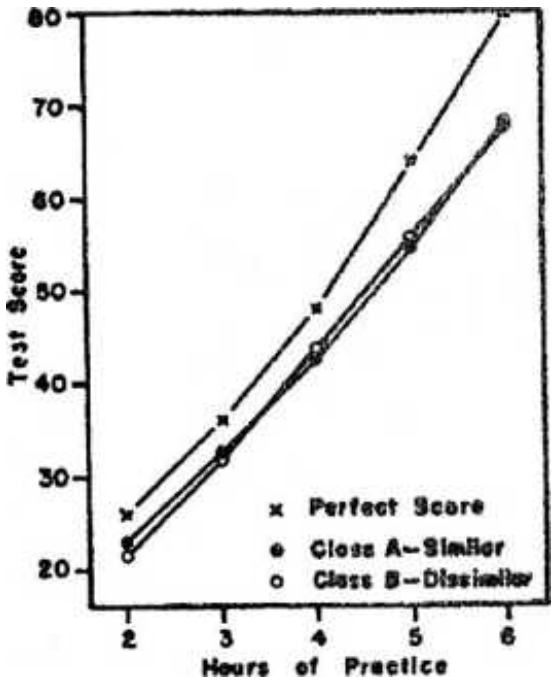
In Class B, this proposed method of presenting dissimilars together was used— but modified because the student learned the first eight characters as a part of an aptitude test in the first hour of practice. Since the conditions and procedures used

[3] J. Degelman, Technique for teaching the radio telegraph code (unpublished), 1942.

in teaching Class B were the same as those used in Class A, in respect of all parameters except this, a comparison of the performances of the two classes will indicate whether teaching dissimilar characters together is actually more efficient.

The exact orders used in teaching the two classes are given in Table I,

Fig. 1 presents a comparison of the mean performances of the two classes during the initial learning of the 40 characters: Fig. 2 a comparison of the rates at which the two classes increased their mean speeds of receiving both meaningful and nonsense material. The results indicate that, although the two classes were taught the characters in different



FIG, 1. GROUPING OF SIMILAR CHARACTERS VS. GROUPING OP DISSIMILAR CHARACTERS

Comparison, in Initial learning, of speed of Class A, in which similar characters were taught together, with speed of Class B, in which groups of dissimilar characters were taught together.

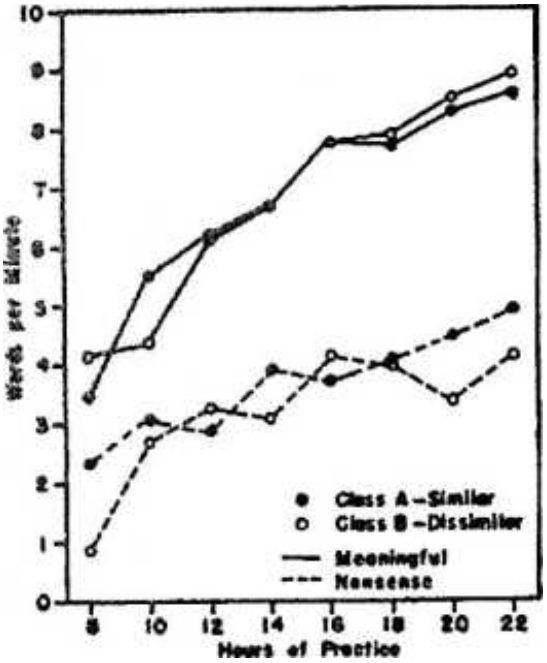


FIG. 2. GROUPING OF SIMILAR CHARACTERS VS. GROUPING OF DISSIMILAR CHARACTERS

Comparison of the mean performances of Class A, in which similar characters were taught together, and Class B, in which dissimilar characters were taught together, in learning to receive nonsense and meaningful material.

orders, there was no significant difference between the mean speeds of learning of the two classes.

Between the 23d and the 40th hours of practice, three students dropped from Class A and three from Class B. Hence the curves in Fig. 2 are not continued beyond the 22nd hour. It seems reasonable, however, to expect that any difference in speed of learning which would result from the difference in the order of the characters would have become evident by the end of the 22nd hour of practice.

Confirmation of this assumption is obtained by comparing the mean attainments, at the end of 40 hours, by the ten students remaining in each class. Table II compares the mean performance in receiving meaningful material of the two sets of ten men.

Fig. 1 shows that when all 13 men in both classes are considered, the mean performance of Class B was slightly superior to that of Class A on the speed-tests given during the 20th and 22nd hours. Table II shows, however, that for the ten men completing each class the mean performance of Class A was actually slightly superior to that of Class B. The explanation of this is that, of the three men dropping from Class A, two were very poor students and the third only average, whereas of the three men dropping from Class B, one was excellent, one average, and one relatively poor.

The slight difference between the two classes at the end of about 40 hours of practice is insignificant. Had all 13 men in both classes completed

TABLE II

	Mean of 20th and 22nd hour tests	Mean of 38th and 40th hour tests
Class A (N=10)	9.5	12.5
Class B (N=10)	8.9	11.6

the course, the relative positions of the two classes at this point might easily have been reversed. In any case, the results indicate no significant difference in the speed of learning in the two classes.

The present experiment was carried out on the assumption that any effect which the variable being studied might have on the speed of learning to receive is relatively independent of the particular manner in which each of the other parameters is controlled. If this assumption, which is implicit in the design of the experiment, is correct—and there is no reason to believe that it is not—then it may be concluded that *whether one teaches similar characters together or dissimilar characters together makes no difference in the speed of learning to receive.*

3. *Speed of Transmission of Individual Characters.* The second problem is one which has already received more attention than any other. The question is whether, in the early stages of learning, the individual characters should be sent at the same slow speed as that of the message as a whole, or whether, from the beginning, the individual characters should be sent at a relatively high speed with long intervals between characters and between words.

Previously published studies[4] of the problem have been unanimous

[4] Taylor, *op. cit.*

in their agreement that individual characters should be transmitted at a high rate of speed from the beginning of learning. The contention has been that at high speeds individual characters are perceived as total patterns, whereas at low speeds they are perceived analytically; *i.e.* in terms of their component dots and dashes.

The method of teaching the individual characters initially at slow speeds forces the student to learn the code analytically. Above a certain rate of transmission, however, it is impossible to perceive the characters in terms of their component dots and dashes. When the student reaches this point, he must change his method of perception and relearn the characters as auditory temporal patterns, thus delaying his progress in receiving.

Therefore, it is argued, individual characters should be sent at a high speed from the first that the students may at once be forced to perceive them as total patterns. There is as yet, however, no adequately-controlled experimental evidence to show that this procedure actually produces any faster learning than does the method of sending individual characters at slow speeds during the early stages of learning.

Further interest in the problem is aroused by the fact that men engaged in teaching code in commercial and military schools of radiotelegraphy do not agree as to the relative efficiency of the two procedures. For many years it has been standard procedure in the United States Army Signal Corps to send individual characters at 20 words per min. throughout the learning process. This practice is predominantly followed in military schools in this country at present Many commercial schools and certain Navy schools, however, do not use such a procedure.

The president of one of the largest commercial schools in the United States reported in a personal conversation with the writer that it had been his experience that sending individual characters initially at high speeds does not produce faster learning than does sending them initially at slow speeds. He stated further that such a procedure tends to make the first stages of learning unduly hard and that, in many cases at least, students actually learn more rapidly when the characters are sent slowly from the beginning.

The problem is worth further experimental investigation.

In Class A (and in Classes B and D), individual characters were, from the beginning of learning, transmitted at a speed of about 18 words per min. Initially the duration of the intervals between characters and between words was such that the messages were transmitted at 3 to 8 words per min. As learning proceeded the speed of transmission was increased by decreasing the duration of the intervals between characters and between

words, the duration of the individual characters remaining constant.

In Class C, the individual characters were transmitted at the same speed as the message, *i.e.* the transmission was such that the relative durations of the dots, dashes, spaces within characters, spaces between characters, and spaces between words, were as defined by international agreement. In the first stages of learning, messages were sent at between 3 and 8 words per min. All other experimental conditions and procedures used in the two classes were the same.

Fig. 3 presents a comparison between the speeds of the two classes in learning the 40 characters during the first six hours of practice: Fig. 4

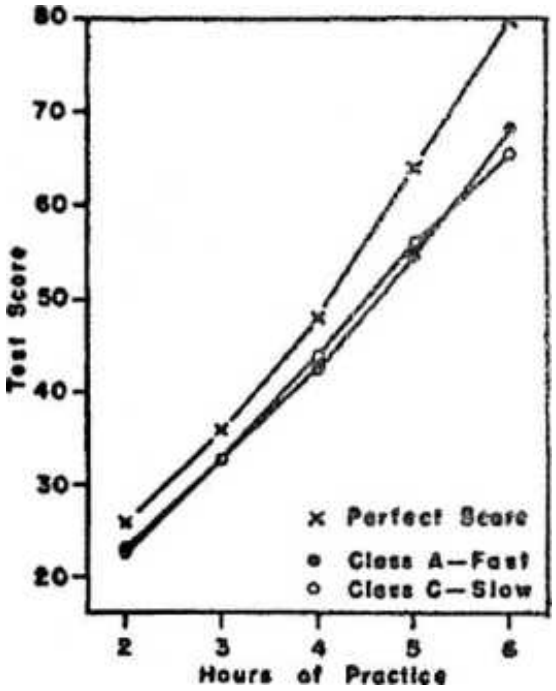


FIG. 3. FAST VS. SLOW TRANSMISSION OF INDIVIDUAL CHARACTERS

Comparison of the speeds of Class A and Class C in initially learning the 40 characters. In Class A the individual characters were from the beginning of learning transmitted at a speed of about 18 words per min. In Class C they were transmitted at the same speed as the messages, the messages being sent initially at relatively slow speeds.

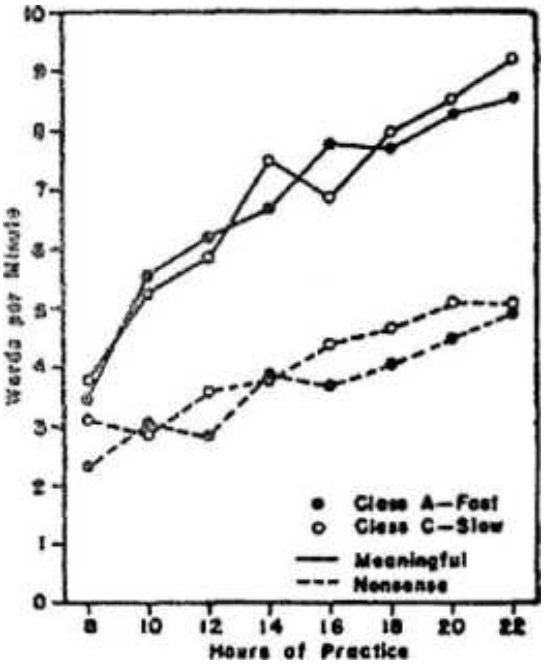


FIG. 4. FAST VS. SLOW TRANSMISSION OF INDIVIDUAL CHARACTERS

Comparison of the speeds of Class A and Class C in learning to receive meaningful material and nonsense material. In Class A the individual characters were from the beginning of learning transmitted at a speed of about 18 words per min. In Class C they were transmitted at the same speed as the messages, the messages being sent initially at relatively slow speeds.

a comparison of the speeds of the two classes in learning to receive meaningful material and in learning to receive nonsense material. These comparisons show that although two different methods were used in teaching the two classes, there was no significant difference in the speed of learning to receive.

Three students, including two very poor students and one of average ability, dropped from Class A between the 23d and the 40th hours of practice, and three men, all very poor students, from Class C. Because of these withdrawals, the curves in Fig. 4 are not continued beyond the 22nd hour of practice.

At the end of this 22nd hour, only 8 of the total of 28 students in Classes A and C had attained a speed of 12 words per min. in receiving meaningful material. This fact raises an important question. The primary reason given for teaching individual characters initially at high speeds is that such a procedure forces the student to learn at once to perceive characters as organized patterns. It is argued that sending characters initially at slow speeds teaches the student to perceive them analytically. It is further contended that, since at high speeds characters must be perceived as organized wholes, the student who thus learns must, when he reaches a certain speed, change his method and learn to perceive characters as wholes. Accordingly, it might be urged that the advantage of learning individual characters initially at high speeds would not become evident until that speed of receiving had been reached where it was necessary to perceive the characters as total patterns. The experiments of Koch[5] have

TABLE III

	Mean of 20th and 22nd hour tests	Mean of 38th and 40th hour tests
CLASS A (N=10)	9.5	13.5
CLASS C (N=12)	9.8	14.0

indicated that this critical point is between 10 and 12 words per min. Thus it becomes important to compare the achievements of the two classes at a point in learning where most of the students in the two classes had attained receiving speeds above this critical point.

By the end of the 40th hour of practice, of the 22 students remaining in the two classes all but 5 had attained receiving speeds of 12 words per min. or above. At the same point, 13 of the 22 had receiving speeds above 15 words per min. and 2 had attained 20 words per min. Comparison of the mean achievement of the two classes at this point would, therefore, seem to provide a conclusive answer to the question just raised.

Table III shows that, contrary to the argument just advanced, Class C not only continued to equal the speed of learning of Class A, but actually showed a slight though insignificant superiority to Class A at

[5] L, Koch, Arbeitspsychologische Untersuchung der Tatigkeit bei der Aufnahme von Morsezeichen, zugleich ein neues Anlernverfahren fur Funker, *A. angew.. Psychol.,* 50, 1936, 1-70.

the end of the 40th hour of practice. The results in Table III, taken with those in Figs. 3 and 4, indicate that although the two classes were taught by different methods, there was no significant difference in the speed with which they learned the code.

In carrying out the present experiment, it has been assumed that the relation between the speed of sending of individual characters, during the various stages in learning, and the speed is independent of the manner in which the other parameters are controlled with which students learn to receive. Unless there is some significant interaction between the speed of transmission of individual characters and some other parameter—and there is no evidence to indicate that there is—it may be concluded that *whether one transmits individual characters at high speeds or at slow speeds, during the progress of learning, makes no difference in the speed with which students learn to receive.*

4. *Technique of Reinforcement.* The third and last problem selected for study was the comparison of the efficiency of the usual method of delayed reinforcement with the efficiency of a method of immediate reinforcement in teaching students to receive.

The usual teaching procedure involves delayed reinforcement. The instructor transmits practice-material for a certain length of time; *e.g.* 2 to 4 min. in the early stages and 15 min. or more in the late stages of learning. Then he stops and reads the material transmitted so that each student may check his own errors. With nonsense material no student can be sure that he has correctly copied the message until such a check-up is made. With meaningful material the speed of transmission is usually maintained at a rate where most students fail to copy the message without errors. In both materials, therefore, it would seem that the ’reward' for correct responses and the 'punishment' for incorrect responses are delayed until the instructor reads the correct message.

Many experiments in the field of learning[4] have shown that reinforcement is most effective when it follows very closely in time the response which is to be learned. As the interval between the response and the reinforcement is increased from such an optimal point, speed of learning is decreased. It might be reasoned that, if in teaching code the interval between the receiving of a character and the reinforcement of that response could be markedly shortened, then the speed of learning to receive would be increased. The present experiment was concerned with a comparison between the efficiency of a method of immediate reinforcement devised by the writer and the efficiency of the commonly used method of delayed reinforcement.

The *method of immediate reinforcement* was used in teaching Class A (and in Classes B and C). During the initial learning of the 40 characters the instructor transmitted a single character. Thereupon each student responded

[6] For a summary of such experiments see E. R, Hilgard and D. G. Marquis, *Conditioning and Learning,* 1940, 251-279.

orally with the name of the character sent. In this manner not only was each man forced to make a response, but he immediately became aware of the correct response. The procedure was varied at times by instructing part of the class to remain silent while the rest of the class responded as usual. During the next stage of learning single words were sent. Immediately after each word the class responded orally as before. During the remainder of the 40 hours of practice, sentences were sent one at a time. After the transmission of each sentence, the instructor read aloud or had the class respond orally with the correct message.

In Class D the *method of delayed reinforcement* was used. During the initial stages the instructor transmitted—not, as in Class A, single characters, but—from 15 to 30 characters each time. Upon the completion of each transmission, the instructor read orally the characters in the order sent. During the remainder of the 40 hours of practice, the instructor sent, as units, messages lasting from 5 to 12 min. Only after the completion of these units were the correct messages read orally. The speed of transmission of the messages was such that relatively few of the students received them perfectly.

As previously described, the procedure used in giving speed-tests in Class A and also in Classes B and C was as follows. The instructor transmitted single-sentence messages one at a time. Following the sending of each message, the correct message was read that the student might check his errors. This is, of course, essentially a method of immediate reinforcement.

Because the speed-tests represented a considerable proportion of the practice which the students received, it was necessary for the purposes of this experiment to modify in Class D the procedure of giving speed- tests, *i.e.* instead of allowing the student to check his work after the receipt of each message, the instructor transmitted the messages in average groups of about four or five. Only after the sending of each group were the correct sentences and nonsense-messages read.

With the exception of the method of reinforcement, the conditions and procedures used in Class D were the same as those used in Class A.

Fig. 5 compares the mean achievement during the first six days of the students in Class A with that of the students in Class D. Fig. 6 compares the rate of increase of the speed of receiving in Class A with that of Class D. The results presented in both figures indicate that, although two different methods were employed in teaching the two classes, there was no significant difference in the speed of learning to receive.

Between the 23d and the 40th hours of practice, three men, including

two very poor students and one of average ability, withdrew from Class A, and one very poor student from Class D. Accordingly, the curves in Fig. 6 are not continued beyond the 22nd hour.

Although there is no reason to expect that the results obtained between the 23d and 40th hours of practice would differ from those obtained during the first 22 hours, for the sake of completeness a comparison is given in Table IV between the mean achievement at about the end of 40 hours of the 10 students remaining in Class A with that of the 16 students remaining in Class D.

Fig. 6 shows that on the speed-test given on the 20th and 22nd hours, the 17 students in Class D had a small and probably chance superiority

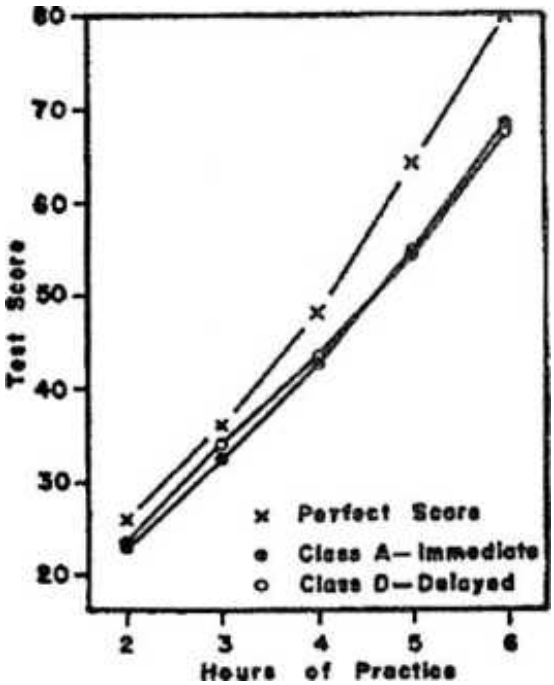


FIG. 3. IMMEDIATE REINFORCEMENT VS. DELAYED REINFORCEMENT

Comparison of the mean achievement, during the first six days, of the students in Class A, in which reinforcement was immediate, with that of the students in Class D, in which reinforcement was delayed.

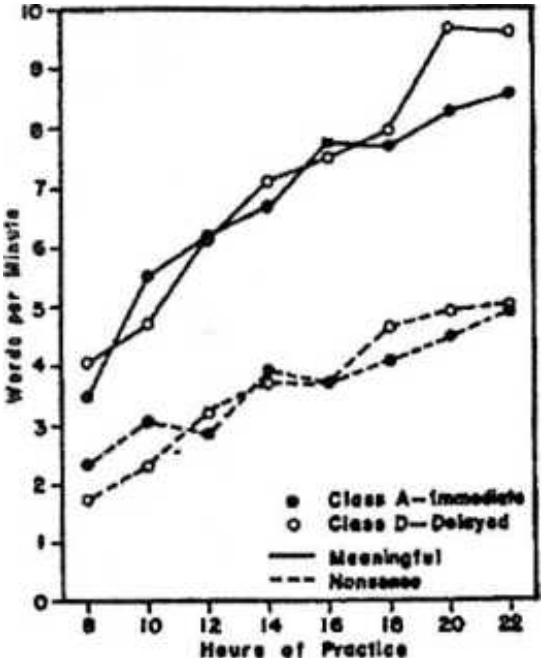


FIG. 6. IMMEDIATE REINFORCEMENT VS. DELAYED REINFORCEMENT

Comparison of the achievement of the men in Class A, in which reinforcement was immediate, with that of the men in Class D, in which reinforcement was delayed, in learning to receive nonsense and meaningful material.

to the 13 students in Class A. This is reflected in Table IV in the fact that at the same point the mean performance of the 16 men completing Class D was slightly but insignificantly superior to that of the 10 men completing Class A. It would seem that the reversal of the relative position of the two classes at about the end of the 40th hour was more apparent than real. In any case, the differences are not sufficient to modify the conclusion, reached on the basis of the first 22 hours of practice, that the difference in

the method of teaching the two classes made no consistent difference in the speed with which the men learned the code.

As in the case of the two previous experiments, the assumption has been made that the effect of the variable under study upon the speed of learning is independent of the manner in which each of the other parameters is controlled. With this qualification, it may be concluded that *the method of immediate reinforcement* (as defined here) *results in no greater speed of learning to receive than does the method of delayed reinforcement* (as defined here).

5. *Effect of Other Variables on Speed of Learning.* Although the differences among the methods with which the four classes were taught produced no significant differences among the classes in speed of learning, nevertheless the rate of learning of the four classes as a group was much faster than is usually expected. When two men who showed an almost complete inability to learn the code are omitted from consideration, the

TABLE IV

	Mean of 20th and 22nd hour tests	Mean of 38th and 40th hour tests
Class A (N=10)	9.5	12.5
Class D (N=16)	10.1	11.9

remaining 46 men attained a mean receiving speed of 13 words per min. after only 40 hours of practice. The speeds attained ranged from 8 to 20 words per min. Forty hours of practice represents a marked reduction from the amount of time usually required to reach such a speed of receiving.

As a general rule, classes require about 80 hours of practice to reach this degree of proficiency. Tulloss' has reported a careful study of the progress of 19 students in a United States Naval Radio School. With three men who made very little progress omitted from consideration, an analysis of Tulloss's data shows that the other 16 required a mean of more than 160 hours of practice to reach a speed of 13 words per min. in receiving meaningful material.

The question may well be raised as to why the rate of learning of our 46 students was much higher than that usually found. Comparison of the procedures used in all of the four classes with those ordinarily used will, of course, not provide a conclusive answer to this question. It will serve, however, to indicate those variables which may have been responsible for the increased speed and therefore suggest those which are most likely to merit further study.

[7] R. E. Tulloss, *The Learning Curve* (unpublished doctoral thesis), Harvard Univ., 1918,

First, it should be pointed out that the *mean altitude* of our *46* students was probably higher than that of the average class in a school in radiotelegraphy. There is no way of knowing whether such a difference in aptitude was in itself sufficient to account entirely for the difference noted. Doubt of this is raised by the finding of Thurstone[8] that aptitude for learning the code shows no correlation with amount of previous education and relatively low correlation with general intelligence. These are the two characteristics in respect of which the students in the four classes differed from students representing a random sample of the general population.

Secondly, distribution of practice-periods in the present study was different from that commonly used. Whereas all of the four classes practiced only one hour a day, five days a week, it is common for students to practice as much as three hours a day. It is interesting to note that the 16 men studied by Tulloss practiced four hours a day. Although they practiced four times as long each day as the men in the present study, they actually took just about as many days to reach the same proficiency. These facts are of course not a conclusive indication that the distribution of practice is important, because there are other uncontrolled differences between the groups. It would seem, however, that this variable is worthy of further study. It is not impossible that massed practice is especially inefficient in learning cede and that an hour a day is almost as effective as four hours. If this is true, then part of the time now given each day to code training could be more profitably devoted to other kinds of training.

Thirdly, in the present experiments speed-tests were given on the average of almost once for every two hours of practice. In many schools speed-tests are given as infrequently as once in 15 or 20 hours of practice. That this difference in procedure may cause some difference in speed of learning seems possible. The speed-tests provide the learner with insight into his performance and motivation for improvement. Insight and motivation are the prime requisites for efficient learning.

Finally, individual learning curves were posted for all students so that each man knew from day to day just how much progress he had made. Although this procedure, as well as the frequent use of speed-tests, would appear to be of considerable importance in arousing and sustaining motivation, It is rarely used in schools of radiotelegraphy.

[8] L. L. Thurstone, Mental tests for prospective telegraphers, /. *appl. Psychol.,* 3, 1919, 110-118.

II. Learning to Send

Students ordinarily make much faster progress in learning to send than in learning to receive. For this reason, the instructional problems of sending have appeared to be of less immediate practical importance. Instruction on sending has therefore—both in the present study and in past studies—received less attention than that on receiving. One important problem, however, is to teach the men to make dots, dashes, and spaces of the proper durations.

We have remarked that a dash at normal operating speeds should be three times that of a dot and that the spaces within individual characters should be equal in duration to dots. The time-length of the spaces between characters and of those between words may vary, depending upon whether the operator first learned the individual characters at a high rate of transmission or whether he learned them at relatively slow speeds and transmitted at the same speed as the messages. At any given speed, successive dots, and likewise successive dashes and successive spaces within characters, should, of course, be equal in duration. Actually perfection in sending is probably never attained except by automatic means of transmission. Nevertheless, the teacher's chief problem in sending is to train the student to attain a close approximation to perfection.

The usual method for practice in sending is to have students work in pairs, one man sending and the other receiving. The criterion of the quality of the sending in this case, is the ability of the other member of the pair to receive the material transmitted. Since most operators can receive relatively poor sending, this criterion may not provide adequate stimulation for improvement in sending. The instructor occasionally listens to the sending of each student and makes suggestions for improvement. Nevertheless, the amount of time he can devote to the individual is of necessity small.

It would appear that more efficient results might be obtained were the student given an opportunity to hear each individual character perfectly sent, followed by a pause during which he could attempt to send the character as he had heard it. In this manner, the student could constantly compare his sending with the goal he is attempting to reach.

To test this hypothesis, a special tape was devised for use in a McElroy Automatic Transmitter. It was so constructed that it would send a character three times followed by an 8-sec. pause, then send another character three times followed by another like pause. This procedure was continued until all 40 characters had been sent. The order of transmission of the characters was random.

An experiment was undertaken to compare the efficiency of this new teaching method of sending with that commonly used.

The men composing the experimental and control groups were drawn from Classes A and B. Because these two classes had been taught by two different methods, it was desirable to avoid taking all of the men for the experimental group from one of the classes and all of the men for the control group from the other. Accordingly, four of the eight men selected for the control group were taken from Class A and four from Class B. Unfortunately, it was necessary to take five of the eight men selected for the experimental group from Class A and only three from Class B. This imbalance probably did not seriously affect the experiment, however, since the difference in the methods used in teaching Classes A and B had actually produced no class-difference in the speed of learning.

Up to the beginning of the experiment, the 16 men, as members of Classes A and B, had received 36 hours of practice in sending and receiving, During the 37th hour of practice, samples of the sending of the students in both the experimental and control groups were recorded. To obtain such samples, an ordinary telegraph key was connected in series with an oscillator, an amplifier, and a McElroy High-Speed Ink Recorder. A pair of type-A Brush Communication phones were connected in parallel with the key so that the operator could hear his own sending. Each student was asked to send the same message, which consisted of nonsense groups varying in length from two to eight characters and contained one each of the 40 characters.

Following the recording of the sending of all the students, both the experimental and the control groups were given an hour-a-day of practice in sending and receiving for a total of eight hours. Both groups spent an average of about 24 min. out of each hour in sending. The procedure used in the two groups differed.

The control group devoted the entire 24 min. each day to the usual kind of practice; that is to say, the students worked together in pairs, one man sending and the other receiving.

In the experimental group only the last half of each 24 min. was spent in the usual kind of sending practice, the first 12 min. each day being devoted to practice with the specially constructed tape described above. By means of this tape and a McElroy Automatic Transmitter, each individual character was sent perfectly three times, followed by an 8-scc. pause. During this pause the student attempted to send the character with his own key just as he had heard it. In this manner, each of the 40 characters was practiced once during the 12 min.

At the end of the eight hours of practice, a sample of the sending of each of the students in both groups was recorded. The same procedure as that employed at the beginning of the experiment was used.

The McElroy Ink Recorder is designed to record up to 300 words per min. It was thus more than adequate for our purposes. The record obtained by its use is an ink line on a narrow paper tape. Dots and dashes are represented by a sudden deviation of the ink-line from its base-position. The action of the recorder is so fast that the beginning and end of each dot and dash are sharply defined. Hence it was possible to measure the length of each dot, dash, and space accurately to the nearest mm.

Analysis of the records proceeded in the following manner. From the 40 characters which each student had sent, 12 were selected as a sample. The 12 chosen from among those judged most difficult to send were the following: Q (— — . —), . (. — . — . —), 8 (— — — . .), 3 (. . — — —), X (— . . —), 2 (. . — — —), L (. — . .), C (— . — .), 7 (— — . . .), Y (— . — —), V (. . . —), Z (— — . .). In each record of a student's sending, the length in mm. of the 27 dots, 27 dashes, and 42 spaces was measured and recorded. In a few cases where extra dots, dashes or spaces had been sent, they were simply disregarded, and where an insufficient number had been sent, corresponding elements in nearby characters were measured and included.

Two measures of the quality of each sample of sending were obtained. The first measure represented the mean duration of the dashes and spaces in terms of that of the dots and was obtained as follows: (1) The mean length of the dots, of the dashes, and of the spaces in each sample of sending was computed. (2) Since the dot is defined as of unit-length for any particular speed of sending, it was possible to express the mean length of the dashes and of the spaces in terms of the mean length of the dot, Two values were calculated for each sample. The mean length of the spaces was divided by the mean length of the dots (S/D) and the mean length of the dash was divided by three times the mean length of the dot (Da/3D). In perfect sending each of these values would of course equal *one.* Actually, however, in nearly every case the dashes and spaces were longer than they should have been with the result that almost all such values were greater than *one.* (3) The mean length of the spaces [$\sum$(S/D)/N] and of the dashes [$\sum$(Da/3D)/N] was computed for both the experimental and the control group before and after the experimental training-period. These values are presented in the first and second columns of Table V. (4) The mean of these two values was then computed to obtain a single measure which would represent the degree to

which the relative durations of the dots, dashes, and spaces in the sending of the men in each group approached those found in perfect sending: [∑ (S/D)/N] + [∑ (Da/3D/N]/2. These measures are given in the third column of Table V.

A second measure was needed to represent the variability of the sending. This was obtained as follows: (1) The standard deviation of the length of the dots, of the dashes, and of the spaces in each sample was computed. (2) To obtain one measure representing the variability of the sending in each sample, the mean of the standard deviations of the

TABLE V

Demean duration of 37 dots in one sample of sending. S=mean duration of 43 spaces. Da=mean duration of 37 dashes. D is by definition a unit of duration in terms of which S and Da can be expressed. S and Da/3 measured in millisec. were almost always longer than D.

	Mean duration of spaces $\sum(S/D)/N$	Mean duration of dashes $\sum(Da/3D)/N$	Mean Duration of spaces and Dashes $(\frac{\sum \frac{S}{D}}{N} + \frac{\sum \frac{Da}{3D}}{N})/2$	Van-ability $\frac{\sum \frac{\delta D + \delta S + \delta Da/3}{3}}{N}$
Experimental				
Before	1.98	1.49	1.73	2.12
After	1.90	1.35	1.63	2.15
Control				
Before	1.85	1.63	1.74	2.41
After	1.78	1.63	1.71	1.96
Perfect Sending	1.00	1.00	1.00	0.00

dots, of the spaces, and of one-third that of the dashes was computed: $[(\sigma D + \sigma S + \sigma Da/3)/3]$. (3) Finally, the mean variability of the sending of the men in each group before and after the experimental training period was calculated: $\sum[(\sigma D + \sigma S + \sigma Da/3)/3]/N$. These values are presented in the fourth column of Table V.

The results presented in the first column of Table V show that although dots and spaces within characters are supposed to be equal in length, the students in the experimental and the control groups tended to make their spaces much longer in duration than their dots. Similarly, although the duration of a dash is supposed to be equal to that of three dots, the results in the second column show the length of the dashes transmitted by both groups was markedly greater than three times that of the dots.

The results summarized in the third column show that the degree to which the men made their spaces and dashes disproportionately longer

than their dots was almost exactly the same in the two groups at the beginning of the training-period. In both groups the slight improvement shown during the experimental training-period was not significant even at the 30-per-cent level as indicated by the t-test. Thus, not only did the experimental group fail to make any greater progress than the control group, but neither made any significant progress in this respect during the training-period.

A comparison of the performance of the two groups in respect of variability of sending is presented in the fourth column. The experimental group failed to show any decrease in variability during the training-period. The use of the t-test for the significance of a difference in the means of related measures revealed that the improvement shown by the control group was not significant at the 15-per-cent level.

On the basis of the results obtained, it may be concluded that *the new procedure described above for teaching sending produces no better results than the usual procedure of allowing the students to send to each other.* It should be noted, however, that this conclusion is definitely limited. It is quite possible that had the two methods been introduced at the beginning of instruction in sending, or had they been continued over a longer period of time, differences in efficiency might have been found. It is unfortunate that the present experiment was limited in its scope by factors beyond the control of the experimenter.

A second and possibly more important conclusion can be drawn. The measurements made in carrying out the present experiment indicate that, although students are given regular sending practice, and although they appear to be able to send-to and receive-from each other proficiently, it cannot be assumed that they have learned to send well. It may be, as in the present case, that the quality of their sending, when measured objectively, will turn out to be relatively poor. The common belief that more difficult problems arise in teaching students to receive than in teaching them to send may actually be incorrect, and may arise from the fact that, while objective measures of the quality of receiving are easily obtained, similar measures of the quality of sending are rarely available. The problems involved in teaching to send are thus in need of further experimental attention.

III. Measurement of Aptitude

1. *Criterion of Code Achievement.* Four classes containing a total of 58 men were used in the investigation of aptitude. The classes were those used in the experiments on receiving and sending, save that the results for

one additional man are here included, a student who learned the code as a member of Class A, but was too irregular in attendance to be used in the previous experiments. Since he put in the required number of hours of practice and took all the tests described, an adequate measure of achievement was available for him, and he brought the total to 59.

Of these 59 men, 11 withdrew from the classes between the 22nd and the 40th hours of practice. Of the 11 men withdrawing, 7 dropped out because they found themselves unable to learn the code. The other 4 men left college for jobs. Because of these withdrawals, it was necessary to take the scores which each man made on the speed-test given during the 22nd hour as a measure of his achievement in learning code.

For each man a single score was obtained to represent his achievement by computing the mean of his speeds in receiving nonsense material and meaningful material. This set of scores was used as the criterion of code achievement with which each of the tests studied was correlated.

The reliability of these scores as a criterion of achievement at this stage of learning was adequate. The correlation between these and similar scores based on the speed-test given during the 20th hour of practice was .93.

A question may be raised, however, as to whether the 22nd hour represents a sufficiently advanced stage in learning to be used as a criterion of ability to learn the code. At this point the speeds attained in receiving meaningful material ranged from 0 to 13.5 words per min. It seems possible that at a later stage in learning the achievements of the students relative to each other might have changed. Fortunately, an answer to this question is available.

By the end of the 40th hour speeds ranging from 3 to 20 words per min. had been obtained. At this point actual measures of achievement were available for 48 of the 59 students. Furthermore, since 7 students had previously dropped out because of inability to learn the code, it seems legitimate to assign to each the lowest score made by a student on the speed-test given during the 40th hour. If this adjustment is made, the correlation between the scores for these 55 men, based on the speed-test given during the 22nd hour, and similar scores representing achievement at the end of 40 hours is .93. It may, therefore, be concluded that the criterion-scores have not only a relatively high reliability, but are also a valid measure of ability to learn code.

Evidence previously described indicates that, although different methods were used in teaching the four classes of students, they may be regarded as random samples from the same population. As a further check on this hypothesis an analysis was made of the variance of the criterion-scores.

Since the variance within classes was actually greater than that between classes, the population of the four classes may be regarded as homogeneous. Accordingly, the 59 men will be treated as members of one group.

2. *Tests Correlated with Code-Achievement.* This part of the investigation was originally undertaken as preliminary to the construction of a test-battery for use in the selection of men for training in code. The immediate purpose was to find a number of tests, each of which had a relatively high correlation with the criterion and a relatively low correlation with every one of the other tests. In the course of the work, however, a single test, the Initial Learning Test, was developed which seemed adequate in itself for use in personnel selection. For this reason, the actual construction of a test-battery was not undertaken. The results of the investigation, nevertheless, are of considerable interest.

Since hearing is the only sense-modality involved in receiving radiotelegraphic code, it would seem that the first step in an attempt to find

TABLE VI

TESTS OP AUDITORY ABILITIES

Test	N	Correlation with Code Achievement
Pitch (Seashore, Series A)	59	.49
Pitch (Seashore, Series B)	59	.56
Loudness (Seashore, Series B)	59	.33
Rhythm (Seashore, Series B)	59	.55
Time Seashore, Series B)	59	.64
Time (Ear her Seashore, Series A)	59	.49
Timbre (Seashore, Series B)	59	.25
Tonal Memory (Seashore, Series B)	59	.56
Rapid Spelling (Karlin)	37	.35
Haphazard Speech (Karlin)	37	.42
Singing (Karlin)	27	.38
Signal Corps Code Aptitude	59	.52

tests correlated with code-aptitude would be the investigation of the possibilities among available tests of auditory abilities. Accordingly, 12 different auditory tests were given. Included were 1 test from the earlier form[9] and 7 tests from the revised form[10] of the Seashore *Tests of Musical Talents,* 3 tests devised by Karlin,[11] and the Signal Corps Code Aptitude Test. Table VI presents a list of the 12 tests together with the correlations found between these tests and code-achievement.

All of the tests except three were given to all of the 59 men. These

[9] C. E, Seashore, *Manual for Measures of Musical Talent.* 1919.

[10] C. E. Seashore, D. Lewis, and J. G. Saetveit, *Manual of Instructions and Interpretations for she Seashore Measures of Musical Talents,* 1939.

[11] J. E. Karlin, A factorial study of auditory function, *Psychometrika,* 7, 1942, 251-279.

three, the tests devised by Karlin, were given only to the 27 students in Classes A and B. For an N of 59, correlations above .33 are significant at the one-per-cent level as indicated by the t-test. With an N of only 27, correlations of .49 or above are required for significance at the one-percent level and of .38 or above at the five-per-cent level.

The tests showing the highest correlation with code-achievement are the Seashore tests of pitch, rhythm, time, and tonal memory.

The correlations of .49 and .56 respectively between the two forms of the Seashore Pitch Test and code-achievement are of the same order as the correlation of .44 found by Lahy[12] between the Pitch Test from the earlier form of the Seashore tests and achievement in code. Since the same frequency is used in transmitting dots and dashes, this correlation between ability to discriminate small differences in pitch and ability to learn code may seem somewhat surprising. A possible explanation is suggested by the fact that pitch has been found to be a function of duration for tones lasting for very short times.[13] Adequate evidence is not available regarding the nature of the functions relating pitch and duration, when frequency and intensity are held constant. Casual observation seems to indicate, however, that, at normal operating speeds, dots and dashes do differ in pitch. If the difference in duration between dots and dashes (at 20 words per min., a dot has a duration of 60 millisec. and a dash of 180 millisec.) does result—either because of the nature of the stimulus produced by the physical apparatus or because of the nature of the response of the ear—in a difference in pitch, a student can take advantage of cues based on pitch-discrimination in distinguishing between dots and dashes.

The correlations of .64 and .49 between code-achievement and the two tests of perception of differences in the duration of intervals do not seem surprising. Lahy,[14] however, found a correlation of only .22 rather than .49 between the earlier form of the Seashore Time Test and ability in learning code. It is interesting to note that the Time Test from the revised form shows a correlation of .64 as compared to the correlation of .49 of the Time Test from the earlier form of the Seashore *Tests of Musical Talent.* The first involves perception of differences in the duration of steady tones, whereas the second involves perception of differences in the duration of pairs of intervals-of-silence whose beginnings and ends are

[12] B. Lahy, Essai d'application des tests musicaux de Seashore a la selection des radiotegraphistes, *C. R. Conf. Int. Psychotech.,* 8, 1935, 241-245.

[13] For a summary of the relevant experimental evidence see S. S. Stevens an*d* H. Davis, *Hearing,* 1938, 100-105.

[14] Lahy, *op. cit.*

indicated by clicks. The first task, of course, is more similar to the task involved in receiving code than is the second.

The correlation of .55 with the Seashore Rhythm Test, Series B, is of the same order as that of .45 found by Lahy[15] between code-achievement and the earlier form of the Seashore Rhythm Test.

The Signal Corps Code Aptitude Test is also essentially a test of the ability to perceive differences in rhythmic patterns. It consists of 78 pairs of patterns of dots and dashes. The dots and dashes forming each single pattern are sent at a rate equivalent to 20 words per min. The task of the student is simply to record whether the members of each pair are the same or different. Although the test is widely used both in this country and elsewhere, men using it report informally that it is low both in reliability and validity and that many of the items included in it are actually nondiscriminating.

The Signal Corps Test was given to the 59 men before they had received any instruction in code. The correlation between the scores on the odd-numbered items and the scores on the even-numbered items was computed and found to be .75. Since the standard deviations of the scores on the odd-numbered items and the scores on the even-numbered items were almost equal, being 3.95 and 3.99 respectively, the use of the Spearman-Brown formula for estimating the reliability of the full-length test was justified. It was found to be .86. The relatively low reliability of the test is probably due in part to the fact that the students would be expected to answer correctly 50 per cent of the items by chance.

The correlation between the code-achievement scores of the 59 men and the scores which they made on the Signal Corps Test was .52. While this coefficient is higher than those reported by men using the test in military schools, the results obtained indicate that the test is inadequate in respect of validity as well as in respect of reliability.

The Revised Alpha Examination Form[16] was given to the 59 men. The results obtained are summarized in Table VII.

In interpreting these results it should be kept in mind that the range of intelligence represented among the 59 men was narrow. The scores attained ranged from 142 to 208 with a mean of 177. All students were, then, among the upper 6 per cent of the population in respect of general intelligence.

In spite of this limited range of intelligence, the results obtained are of

[15] *Ibid.*

[16] F. L. Wells, *Revised Alpha Examination, Form* 7, 1933.

the same order as those found by Thurstone[17] on a larger and, in this respect, more representative group.

Two points are worthy of particular notice. First, the correlation of .39 between ability to learn code and the sum of the scores on the mathematical tests is almost the same as that of .*42* between such ability and the sum of the scores on the verbal tests. Secondly, the correlation of .46 between the Directions Test alone and the criterion is almost as large as that of .50 between the total Alpha score and the criterion. This second relation would suggest that, if a test-battery were being constructed, the possibilities of using the Directions Test as one element should be investigated. Actually, in one case reported informally to the writer, a similar

TABLE VII

TESTS OF MENTAL ABILITIES

N=59

Test	Correlation with Code Achievement
Revised Alpha Examination Form 7	.50
Individual Alpha Tests	
1. Addition (as scored by writer)	.40
2. Arithmetic Problems	.15
3. Common Sense	.27
4. Same-Opposite	.38
5. Mixed Sentences	.22
6. Numerical Relations	.38
7. Word Relations	.38
8. Directions	.46
Sum of Scores on Mathematical Tests (1, 2, 6)	.39
Sum of Scores on Verbal Tests (3, 4, 5, 7)	.42
Scholastic Achievement (N=52)	.22

test has been used together with tests of auditory and motor function in a battery employed in the selection of men for training.

The Addition Test consists of five columns of 22 items each. Ordinarily, the student is instructed to begin at the top of one column, the number of which is announced by the examiner, and to complete as many as possible of the items in that column before time is called. The writer knew, however, from a test given previously that a majority of the men would complete the single column in the time allowed, and that therefore the test would be non-discriminating. Because of this, the instructions for the test were changed. The students were told to begin on the column whose number was to be announced by the instructor and, if they finished that column, to go on to the next column and continue working until time was called. The test was scored in two ways. First, each student was given a score based only on the items which he had completed in the first column.

[17] Thurstone, *op. at.*

This score was used in the computation of the total Alpha score. Thus the change in instructions for the Addition Test made no change in the resulting total Alpha scores. Secondly, each student was given a score representing the total number of items which he completed correctly. These scores were used in computing the correlation of the Addition Test alone with achievement in code. The correlation of .40 is significant at the one-per-cent level and indicates that there is a definite relation between this test and the criterion.

Each undergraduate in Harvard University is assigned to one of six groups on the basis of his scholastic achievement. Those who have made the best mean grade in their college courses are placed in Group I, the next best in Group II, and so on. Such measures of achievement were available for 52 of the 59 men. The correlation between the group-ranks of the individual men and their code-achievement scores was —.22. In other words, the correlation between achievement in college and achievement in learning code was .22, a coefficient not significant at the ten-per- cent level as indicated by the t-test. This result seems to be consistent with Thurstone's finding[18] that there is a zero correlation between the ability to learn code and the amount of education which an individual has had.

In a personal conversation with the writer, the commanding officer of one naval radio school stated that it was his belief that one of the important factors in aptitude for learning code is the ability to react quickly to an auditory stimulus with the proper controlled association. To test this hypothesis, the Controlled-Association Reaction-Time Test was given to each of the 32 men in the fall classes.

The procedure used was as follows. Two voice keys were connected with a vacuum-tube circuit and a chronoscope in such a way that the activation of one key would start the chronoscope and the activation of the second key would stop it. The instructor used the first key, the student being tested the second. Letters of the alphabet spoken in random order by the instructor were the stimuli employed. The student was instructed to respond to each letter as quickly as possible with the letter immediately following it in the alphabet. Three practice trials and ten test trials were given. False responses were not recorded, and additional trials were substituted for them. The time consumed in reacting on each trial was recorded in millisec. The mean of the reaction times on the ten test trials was taken as the student's score.

The mean reaction times obtained varied from 57 to 105 centisec. with a mean of 94.4 and a standard deviation of 9.7. The correlation between

[18] *Ibid.*

reaction-time scores of the 32 men and their code-achievement scores was —.45. In other words, the correlation between speed of reaction and ability to learn to receive was .45. With 32 students, a correlation of .45 is just significant at the one-per-cent level.

In an attempt to find a test which would measure speed of reaction and which could be given as a group test, the Digit-Cancellation Test was devised. Sheets were obtained upon which were printed 20 rows of digits, each row containing 50 digits, with an equal number of each of the digits from 0 to 9. The order in which the digits appeared was random. The test lasted two minutes. The students were instructed to cross out with a single stroke each 3 and each 7 and to work as rapidly as possible. Each student was given as his score the number of 3s and 7s which he had crossed out within the time limit. The scores attained ranged from 74 to 146 with a mean of 104.0 and a standard deviation of 16.7. The correlation between the scores of the 32 men in the fall classes on the Digit-Cancellation Test and their achievement in code was .45. It is interesting to note that the correlation between the speed of reaction as measured by this Digit-Cancellation Test and the criterion is the same as that between the criterion and speed of reaction as measured by the Controlled-Association Reaction-Time Test.

In an attempt to devise an abbreviated visual analogue of the task involved in learning to receive, the Digit-Symbol Substitution-Learning Test was constructed. First of all, ten simple nonsense figures were drawn, that is to say, simple line-drawings not resembling any familiar object were devised. A key was prepared in which each of the digits between 0 and 9 inclusive was paired with one of the nonsense figures. Next a sheet was prepared on which ten rows of 20 nonsense figures appeared, thus making a total of 200 nonsense figures. Beneath each figure was a square in which a digit could be written. One mimeographed copy of the key and three mimeographed copies of the sheet were made for each student

The test period was divided into three parts. Before the test began, the students were told that they would have a learning period of 2.5 min., followed by a rest period of 1 min., and then by a test period of 2.5 min. They were instructed to use the first period to learn the digits corresponding to each of the nonsense figures, and were told to practice by referring to the key and by filling in the squares beneath nonsense figures on one of the sheets with the appropriate digits. At the end of the learning period, each student placed his key and practice-sheet face down on his desk.

At the beginning of the test-period, the students were instructed to leave their keys and practice-sheets face down and to take an unused

sheet. They were then told to work as fast as possible and to fill in on the test-sheet the digits corresponding to the nonsense figures. They were further instructed that, if they finished one sheet before the end of the time limit, they must begin immediately on a second sheet.

Each student received as his score the number of digits which he had filled in correctly during the test-period, minus the number filled in incorrectly. The scores attained ranged from 39 to 243, with a mean at 150.2 and a standard deviation of 52.8. The correlation between scores made by the 32 students in the fall classes and code-achievement scores was .28 and not significant at the five-per-cent level as judged by the t-test.

3. *The Initial Learning Test.* Lipmann[19] and Koch[20] have both suggested that a valid estimate of a man's ability to learn to receive may be made on the basis of the speed with which he learns the first few characters of the code. Neither, however, has explored adequately this possibility. To test this hypothesis the Initial Learning Test was constructed.

The test was designed to provide one measure of the speed with which students learn under controlled conditions eight characters: F (. . — .) , C (— . — .) , 2 (. . — — —) , 9 (— — — — .), period (. — . — . —) , comma (— — . . — —), question mark (. . — — . .) , and fraction bar (— . . — .) . These particular eight characters were selected only because they are among those usually unknown to beginning students. The test is divided into two main parts, the learning-period and the test-period.

The learning-period itself is divided into three parts. First, each character is announced in turn and then sent three times so that the students can hear how it sounds. This procedure is continued until each of the eight characters has been announced five times, the time required being about 9 min. Secondly, individual characters are first sent three times and then followed by a pause of about 6 sec. The students are instructed to attempt during this pause to write down the symbol for the character just sent. Following the pause the name of the character sent is announced so that each student may find out whether he was right or wrong. In this manner the eight characters are presented in random order three times, the time required being about 7 min. Thirdly, the characters are sent in groups of three, each character being sent only once. Following the transmission of each group of three characters, there is a pause of about *6* sec. during which the students as before write down the symbols for the characters just heard. Following this pause the names of the three characters sent are

[19] O. Lipmann, Die psychische Eignung der Funkentelegraphiten, *Ztschr. angew. Psychol.,* 15, 1919, 301-340.

[20] Koch, *op. cit.*

announced. This procedure is continued until 32 groups of three characters each have been presented, the time required being about 14 min. Thus, the students are given a total of about 30 min. of practice in learning the eight characters.

Following the half-hour learning-period a test requiring about 20 min. is given. The test is composed of 100 items and includes each of the eight characters ten times, together with a total of twenty characters which the students have never heard before. The order of the items is random.

The procedure used in presenting each item is as follows. The number of the item is first announced. Then a character is sent once, followed by a pause of 5 sec. If the character is one of the eight presented during the learning period, the student records the symbol for it in the appropriate space on the special mimeographed blank with which he was provided at the beginning of the test, If the character is one which he has never heard before, the student indicates this fact by placing a zero in the appropriate space.

To insure that successive repetitions of the test were comparable, the entire Initial Learning Test, including the instructions, the practice material, and the test itself, was phonographically recorded. The records were used in presenting the test to each of the four classes during the first hour of learning.

Each student received as his score the number of items which he identified correctly. The scores attained by the 59 men ranged from 12 to 100, the mean score being 68.7 and the standard deviation 25.2.

An estimate of the reliability of the test was obtained by the split-half method. The correlation between the scores made on the odd-numbered items and those on the even-numbered was .94. This, of course, represents the reliability of a 50-item test. Since the variance of the scores on the odd-numbered items was, however, about equal to that of the scores on the even-numbered items, the standard deviations being 12.7 and 12.9 respectively, the Spearman-Brown formula could be used to estimate the reliability of the full-length test. The coefficient of reliability for the Initial Learning Test obtained by the use of this formula is .97.

These results indicate that the reliability of the test is quite adequate. In fact, if it were necessary to do so to save time, it might be feasible to use a test containing only 50 items, since the results indicate that the coefficient of reliability of a test of this length is .94. Shortening the test, however, would of course result in a slight decrease in its validity.

The correlation between the scores of the 59 men on the Initial Learning Test and their scores based on the speed-test given during the 22nd hour

of practice was .71. Correction of this coefficient only for attenuation in the criterion yields a validity coefficient of .73. Thus, by usual standards, the test would be judged to be sufficiently valid for predictive purposes, particularly since the reliability of the test is high.

It is interesting to note that the correlation between the scores of 55 men on the Initial Learning Test and their scores based on the speed-test given during the 40th hour of practice was .69, this coefficient having been corrected for attenuation in the criterion only. Since at this point speeds varying from 3 to 20 words per min. had been attained, this fact gives further confidence in the validity of the test.

Still another check may be made on the test's validity. In the actual selection of personnel the test-scores would be used to divide the men tested into two groups, the apt and the inapt. Because it gave the highest percentage of correct predictions in the present sample, 35 was selected for use as the critical score. Of the 59 men, 9 made scores below this value. On the basis of 40 hours of practice, 9 students were judged to be inapt. Of the 9 who made scores below 35 on the Initial Learning Test, 7 were among those judged after 40 hours of practice actually to be inapt. In other words, 2 students judged inapt on the basis of the test actually turned out to be apt and 2 students judged apt by the test actually turned out to be inapt. Thus, predictions made on the basis of the test would have been correct for 55 out of the 59 students or 93 per cent of the men.

Similarly, the achievement of the best students in the course could be predicted well on the basis of the scores on the Initial Learning Test. The 6 best men all made scores of 94 or above. Of the 14 best men, 10 made scores of 90 or above, and the other 4 made scores above 65.

None of the 59 men to whom the Initial Learning Test was given had had experience in the use of the code prior to the taking of the test. The question may be raised as to whether the test would be equally valid for the selection of personnel if it were given to a group of men, part of whom had had some prior knowledge of at least some of the characters.

As a first step toward obtaining an answer to this question, an experiment was carried out to determine whether a knowledge of a certain number of characters facilitates the learning of additional characters. After Classes C and D had had 33 hours of practice in the use of 40 characters, they were given a test identical in every respect with the Initial Learning Test with two exceptions. First, this test was not recorded. Secondly, 8 new characters, which they had not previously learned, were substituted for the ones usually taught in the Initial Learning Test. The 8 new characters were: semi-colon (— . — . — .), colon (— — — . . .),

quotation marks (. — . . — .), apostrophe (. — — — — .), parenthesis (— . — — . —), dash (— . . . —), hyphen (— . . . . —), and dollar mark (. . . — . . —).

The mean of the scores made by the 32 men in Classes C and D on the Initial Learning Test was 70.7. The mean of the scores made by the same men on the test given after 33 hours of practice was 88.4, all of the men but 7 making scores above 90. If it may be assumed that, as seems highly probable, the 8 characters in the test given after 33 hours were at least as difficult inherently as the 8 characters taught in the Initial Learning Test, then these results indicate that knowledge of a certain number of characters docs aid in the learning of new characters. Thus, it would appear that men knowing some characters in the code, even though they did not know the particular ones used in the test, would tend to make higher scores on the Initial Learning Test than those having no such prior knowledge.

This fact does not imply, however, that the Initial Learning Test would necessarily be less valid when given to a group of men, part of whom had some prior knowledge of code. Although it sounds paradoxical, the inclusion in a test-group of men having some prior knowledge might even lead to an increase rather than a decrease in the validity coefficient.

This consequence might ensue for the following reason. Men knowing even a very' few characters upon entrance into a radiotelegraphic school are known ordinarily to learn the code markedly faster than those having no such prior knowledge, a fact which has been demonstrated by an analysis made by the writer of the progress of the students in one class in a naval radio school. Of 102 students there, 79 had had no previous experience in the use of the code. Of these 79 men, 37 per cent turned out to be poor students and only 15 per cent were very good students. In contrast with them, among the 23 men with some prior knowledge of code—in many cases a very slight knowledge—only 13 per cent were poor students and 52 per cent were very good students.

It is to be seriously doubted that the possession of prior knowledge is a chief cause of the superior performance of the men possessing such knowledge. The actual proficiency of these men upon entrance is too low to give them any marked advantage over a period of months. It is more probable that the possession of prior knowledge and the superior performance are both the result of superior aptitude for learning code.

No matter what the causes may be, the fact is that men possessing slight prior knowledge of code tend both to make high scores on the Initial Learning Test and to be superior in performance in learning the

code over a period of months. Therefore, the inclusion of men possessing such knowledge in a group being tested will not decrease—may in fact increase—the validity of the test. Such an increase may occur because the inclusion of such men would result in the presence in the group being tested of a greater proportion of men making high scores both on the test and in achievement in code. *Ceteris paribus,* the greater the dispersion of the scores, the higher will be the coefficient of validity.

SUMMARY

The present war demands the rapid training of a very large number of men in the use of the International Morse Code. This paper examines some of the parameters of the learning of receiving and sending of radiotelegraphs code and proposes speed of initial learning as a test of aptitude for learning code.

I. *Receiving.* Contrary to expectations, this study shows that it makes no difference in speed of learning whether similar or dissimilar characters are grouped together for learning.

Again contrary to expectations, the results obtained indicate that it makes no difference in the speed of learning whether the speed of sending of the individual characters is varied from low to high speeds with increase in speed of sending of the messages, or whether each individual character is sent from the beginning at a normal operating speed and the messages are sent at slower speeds by increasing the duration of the spaces between the characters. It has been supposed that the individual characters should from the start be sent at a normal speed so that each would be perceived as a total pattern and not as a succession of dots and dashes.

The use of a method of immediate reinforcement produced no faster learning than did the use of the method of delayed reinforcement ordinarily employed.

The students in all four of the classes employed in the present experiments learned to receive in about one-half of the time that is usually required, Among the factors which might have been responsible for this superior performance are superior aptitude, better distribution of practice, and a higher degree of motivation resulting from the use of frequent speed-tests and the use of individual progress-charts.

II. *Sending.* Men ordinarily learn to send more rapidly than they learn to receive. Hence the teaching of sending has received less attention.

One important problem, however, is that of teaching the men to make their dots, dashes, and spaces of the proper durations. In an attempt to meet this problem a method of training was devised whereby the students

attempted to duplicate the transmission of characters as sent perfectly by an automatic transmitter. It was found, however, that this method was no more efficient than the usual procedure of having students practice by sending to each other.

Objective measurements of the sending of the students also showed that, although students are given regular sending practice and although they appear to be able to send to, and receive from, each other proficiently, the quality of their sending may actually be relatively poor.

III. *Aptitude.* From 30 to 60 per cent of the men entering schools of radiotelegraphy fail to become proficient operators. The Signal Corps Code Aptitude Test, the only test used on a large scale in this country, is low both in reliability and validity and is not adequate for use in personnel selection.

Among 11 auditory tests, those showing the highest correlation with achievement in code were the Seashore tests of pitch, rhythm, time, and tonal memory. General intelligence showed a correlation of .50 with code achievement, whereas no significant correlation was found between such achievement and college grades.

Among all the tests given, the Initial Learning Test was found to yield the best prediction of eventual achievement in code. It is high both in reliability (.97) and in validity (.73) and is the best test yet developed for use in the selection of men for training in code. Its use in personnel selection may be expected to reduce greatly the proportion of failures among men in training.