REPORT RESUMES

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THE RELATIONSHIP BETWEEN AGE AND INFORMATION PROCESSING
CAPACITY OF ADULTS. REPORT NUMBER 7.

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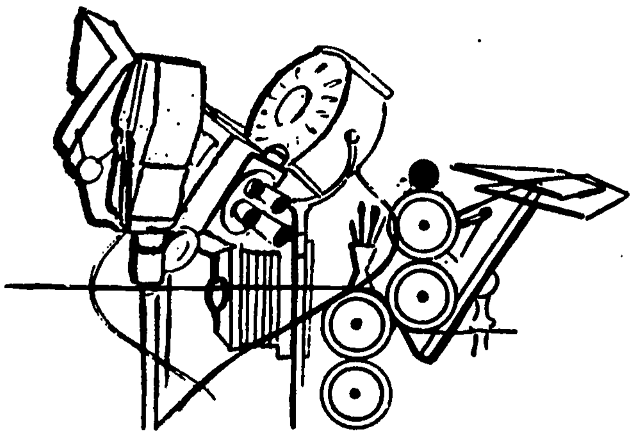
CHANGE IN INFORMATION PROCESSING AND CHANNEL CAPACITY WITH INCREASE IN AGE WAS STUDIED, AND POSSIBLE ALTERING OF THIS RELATIONSHIP WITH A CHANGE IN COMPLEXITY AND DIMENSIONALITY OF THE STIMULUS PRESENTED. VISUAL STIMULI WERE PROJECTED ON A SCREEN TO FOUR GROUPS COMPOSED OF 74 COLLEGE GRADUATES, RANGING IN AGE FROM 23 TO 68 YEARS, IN A SIMULATED CLASSROOM. THREE OF FIVE TESTS WERE PRESENTED TO EACH SUBJECT--SIZE OF DARK SQUARES ON LIGHT BACKGROUND WAS JUDGED IN THREE TESTS, AND LOCATION OF DOT PLACEMENT IN A GRID PATTERN IN TWO TESTS. ABSOLUTE JUDGMENTS WERE USED TO MEASURE JUDGMENTAL DISCRIMINATION ACCURACY. INFORMATION THEORY STATISTICS WERE USED FOR INDIVIDUAL TEST DATA ANALYSIS, AND CONVENTIONAL STATISTICS TO DETERMINE LEVELS OF SIGNIFICANCE OF DATA COLLECTED. IT WAS FOUND THAT PERFORMANCE DECLINED AS AGE INCREASED IN THREE OF THE FIVE TESTS, CONTAINING THE LEAST COMPLEX STIMULUS SITUATION, WHICH WAS CONTRARY TO PREDICTION. IT WAS SPECULATED THAT A HIGHER ANXIETY RATE WAS MANIFESTED DURING EARLY TESTS, AND OLDER SUBJECTS REACHED PEAK PERFORMANCE DURING THE THREE LATER TESTS. ALL SUBJECTS SCORED HIGHER ON THE MULTIDIMENSIONAL STIMULUS PRESENTATIONS (DOT AND SUBJECTS SCORED HIGHER ON THE MULTIDIMENSIONAL STIMULUS PRESENTATIONS (DOT AND GRID). OTHER FINDINGS SHOWED MALES OUTSCORING FEMALES IN ALL TESTS. (PT)

The Relationship Between Age and Information Processing Capacity of Adults



REPORT NO. 7

DEPARTMENT OF AGRICULTURAL INFORMATION
NORTH CAROLINA STATE UNIVERSITY
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The Relationship Between Age and Information Processing Capacity of Adults

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Report No. 7

Department of Agricultural Information
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April, 1968

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Contents

Introduction

Statement of the Problem

The aging process of the human organism is of considerable concern to the adult educator since it has been demonstrated that a number of factors associated with age have a bearing on the adult as student and learner.

Specifically, the question has revolved around the ability of the middle-age and older adult to learn. Many adults avoid adult education because of their firm belief that they are "too old to learn."[1] Interest in this area has been heightened as the Nation has committed itself to the notion that all citizens should be trained to the extent that they can find employment and satisfying living in a technological society.[2] This raises the question as to the possession by older citizens of the necessary abilities and capacities for education and training.

Although research has proven beyond doubt that older people can learn, there is a known decline in certain kinds of learning abilities, or in learning under certain circumstances as age progresses through the middle and later years.[3] However, there is need for new approaches to the study of adults to determine their various capacities for learning. This study represents an exploratory effort in this direction.

Methodology Used

A mathematical model developed by information theorists has provided a tool useful in measuring certain human characteristics. Specifically, it has been used to answer two fundamental questions

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[1] James R. Kidd, How Adults Learn (New York: Association Press, 1959).

[2] Federal Support for Adult Education: A Directory (Washington, D.C.: Adult Education Association of the U.S.A., 1966).

[3] Edward L. Thorndike, Adult Learning (New York: The Macmillan Co., 1928); Irving Lorge, *et al.*, Psychology of Adults, Adult Education Theory and Method Series (Chicago: Center for the Study of Liberal Education for Adults, 1963). (Pamphlet.)

about the information processing capacity of the human organism: How much; and How fast? To answer these questions, two separate lines of research have been pursued in the past 15 years. The first, concerned with "how much" has dealt with the number of alternative absolute judgments a subject can correctly make along a given stimulus dimension. The second has been concerned with the rate of gain, or the speed with which such judgments can be made.[1]

Both lines of research make use of the terms <u>information processing capacity</u> and <u>information channel capacity</u>. These terms are defined here in reference to the information processing ability of the human organism when it is acting as a communication system. Information channel capacity is considered to be the maximum amount of information which can be transmitted through a given channel in a communication system in a given time when the channel itself is the limiting factor. Information processing capacity refers to the amount of information which can be transmitted when the above channel capacity limitation is not the limiting factor or the only limiting factor at work.

Although this methodology has been used considerably by psychologists, the effects of aging or the relationship between age and information processing capacity has not been fully assessed. In this study the use of absolute judgments to measure judgmental discrimination accuracy and information processing capacity was extended to measure subjects over a 45-year age range and under simulated classroom conditions. Using visual stimuli, 74 subjects judged size of dark squares on a light background in three tests and the location of the placement of a dot in a grid pattern in two tests. Information theory statistics were used for individual test data analysis, and conventional statistics were used to determine levels of significance of the data collected.

The purpose of this study was to determine (1) if there is a change in information processing and channel capacity as the human organism grows older; and (2) if the relationship found in (1) is altered with a change in stimulus complexity.

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[1] Michael E. Doherty, "Information and Discriminability as Determinants of Absolute Judgment Choice Reaction Time" (unpublished dissertation, University of Connecticut, 1965), p. 2.

Theoretical Framework

Aging and Physiological Change

Aging is a process affecting all living organisms. Medical science has been able to chart rather specifically the aging process of the various parts of the human organism, ranging from the moment of fertilization until death, but without shedding much light on why it occurs.[1]

This process can be divided into two stages: growth or evolution; and atrophy, shrinkage or involution. It is generally conceded that both stages are at work throughout the life span, although growth is predominant until maturity. In the later years atrophy exceeds growth, but certain things continue to grow in the healthy organism until the end--the mind, for example.[2]

Hand lists several major biological changes in the human organism correlated with aging that have relevance to education: (1) decline in visual acuity; (2) loss of hearing; (3) diminishing motor abilities; (4) decreased speed, strength, and endurance of skeletal neuromuscular reactions; (5) degeneration of the nervous system with impaired attention, memory and mental endurance; and (6) gradual aging of tissue, cells, and other organs of the body.[3]

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[1] Geoffrey H. Bourne, "Structural Changes in Aging," in Aging--Some Social and Biological Aspects, ed. by Nathan W. Shock (Washington, D.C.: American Association for the Advancement of Science, 1960), pp. 123-136.

[2] Edward J. Stieglitz, "Do You Want to Live Longer?" Interview, U. S. News and World Report, Vol. 44 (Feb. 14, 1958), pp. 74-83, reprinted in Old Age in America, ed. by Gladys Engel Lang (New York: H. W. Wilson Co., 1961), p. 93.

[3] Samuel E. Hand, A Review of Physiological and Psychological Changes in Aging and Their Implications for Teachers of Adults (Tallahassee, Fla.: The State Department of Education, Bulletin 71G-1, 1965), pp. 2-8. (Pamphlet.)

Of particular concern in this study are the physiological changes relating to visual acuity and reaction time. Several authors, particularly Hand and Birren[1] have summarized research dealing with vision and reaction speed changes brought about by aging. They show that visual acuity attains its maximum at about age 18 and declines continuously thereafter; a gradual narrowing of the visual field; decline in perceptual ability; a slowing down of dark adaptation (peripheral vision); more color blindness; a loss of efficiency in the pupillary mechanism; and a gradually higher threshold for light stimulation for men past the fourth decade.

The increase of simple reaction time with advancing age has been well documented.[2] But the effects of age are greater in complex choice reaction times than in simple responses.[3] Birren cites several studies which show that in simple auditory and visual reaction time there is a 10 to 20 per cent slowing between 20-year-olds and 60-year-olds (from .20 to .22 seconds). In another study there was an increase over approximately the same age range of .011 seconds in simple reaction time, .057 seconds for a two-choice reaction time, and .066 seconds for a five-choice reaction time. Birren concludes that whatever the ultimate neurophysical nature of slowing with age involved in simple reaction time, it seems to become increasingly involved in complex choices.[4]

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[1] James E. Birren, The Psychology of Aging (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1964), pp. 81-92, 105-107.

[2] A. D. Weiss, "The Relation of A-wave Latency of the Electroretinogram to Human Aging," Journal of Gerontology, Vol. 11 (Oct., 1956), pp. 448-449; Jack Botwinick and Larry W. Thompson, "Components of Reaction Time in Relation to Age and Sex," Journal of Genetic Psychology, Vol. 108 (June, 1966), pp. 175-183.

[3] Nathan W. Shock, "Some of the Facts of Aging," in Aging--Some Social and Biological Aspects, ed. by Shock, p. 251.

[4] Birren, op. cit., pp. 120-121.

To summarize, there is a general slowing down of the human organism as it ages, and as the complexity of the stimuli presented increases the organism is slower to respond. As the organism grows older this slower response as stimulus complexity increases is accentuated.

Information Theory and Psychology

Man's concern with communication surely antedates the development of alphabets and writing which today have become principle communication tools. But it has been within the life-span of many living today that man has effectively provided a scientific framework for the process called communication.

In 1894 Boltzmann, in some of his work on statistical physics, observed that entropy was related to missing information, inasmuch as it was related to the number of alternatives which remained possible to a physical system after all the macroscopically observable information concerning it had been recorded.[1]

In 1924 Nyquist and Kupfmuller stated the law that, in order to transmit telegraph signals at a given rate, a definite bandwidth is needed. In 1928 Hartley expounded on this law and showed that in order to transmit a given quantity of information a definite product (bandwidth x time) is required. He defined information as the successive selection of signs or words from a given list, and stated that the "quantity of information is most reasonably defined as the logarithm, that is, $H = N \log S$."[2]

During the World War II period, Shannon and Wiener were independently giving considerable thought to the information-communication process. Wiener, particularly interested in biological application of the process, is credited with much of the basic philosophy and theory of communication.[3] Shannon,

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[1] Claude E. Shannon and Warren Weaver, The Mathematical Theory of Communication (Urbana, Ill.: University of Illinois Press, 1949), p. 95.

[2] Colin Cherry, On Human Communication (New York: John Wiley and Sons, Inc., 1957), pp. 42-43.

[3] Norbert Wiener, Cybernetics (New York: The M.I.T. Press and John Wiley and Sons, Inc., 1948).

working in the Bell Telephone Laboratories, was more concerned with the application of theory to engineering communication.[1]

Shannon's communication model,[2] which has stimulated much research in communication, psychology, and other areas, can be diagrammed as shown in Figure 1.

The development of information theory created interest in a number of diverse directions, as illustrated by Figure 2 which presents the author's schematic diagram designed to categorize this activity.

Based primarily on R. A. Fisher's application of the term "information" to statistical data (The Design of Experiments, Oliver & Boyd, Ltd., 1935) there was some effort to apply the information theory, particularly the statistical concepts, to a wide variety of scientific disciplines.[3]

A number of communications researchers have attempted to adopt the original Shannon concept to the practical side of human communications.[4] Their models have become the basis for the development of a discipline of human communications and guides for research and application to both intrapersonal and interpersonal communication (Communications theory and practice, Fig. 2).

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[1] Shannon and Weaver, op. cit., pp. 52-53, 95.

[2] Ibid., p. 5.

[3] Henry Quastler (ed.), Essays on the Use of Information Theory in Biology (Urbana, Ill.: University of Illinois Press, 1953).

[4] Wilbur Schramm, "How Communication Works," in The Process and Effects of Mass Communication, ed. by Wilbur Schramm (Urbana, Ill.: University of Illinois Press, 1954), pp. 3-26; Bruce Westley and Malcolm S. McLean, Jr., "A Conceptual Model for Communications Research," Audio-Visual Communications Review, Vol. 34, No. 3 (1955), pp. 3-12; George Gerbner, "Toward a General Model of Communication," Audio-Visual Communications Review, Vol. 35, No. 4 (1956), pp. 171-199; David K. Berlo, "A Model of the Communication Process," in his The Process of Communication (New York: Holt, Rinehart and Winston, 1960), pp. 23-39.

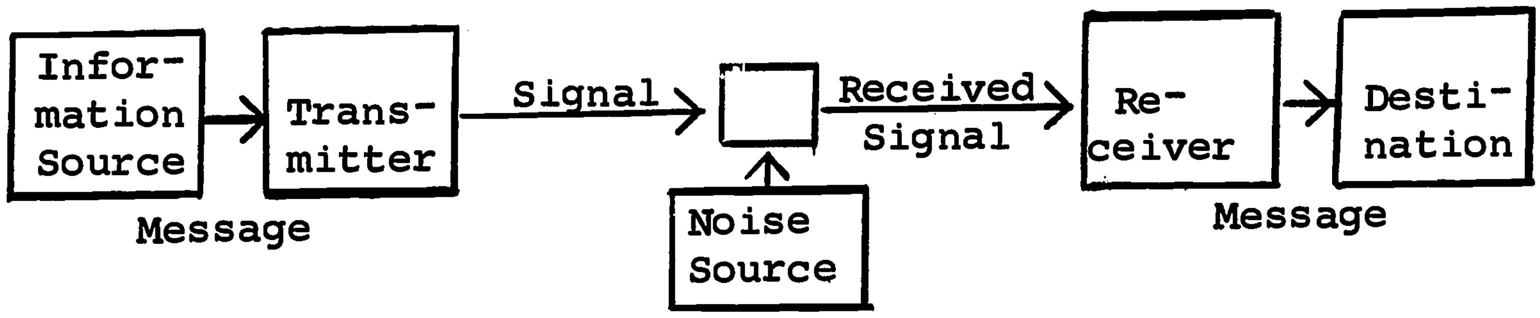

Fig. 1. A communication model (Shannon and Weaver, 1949)

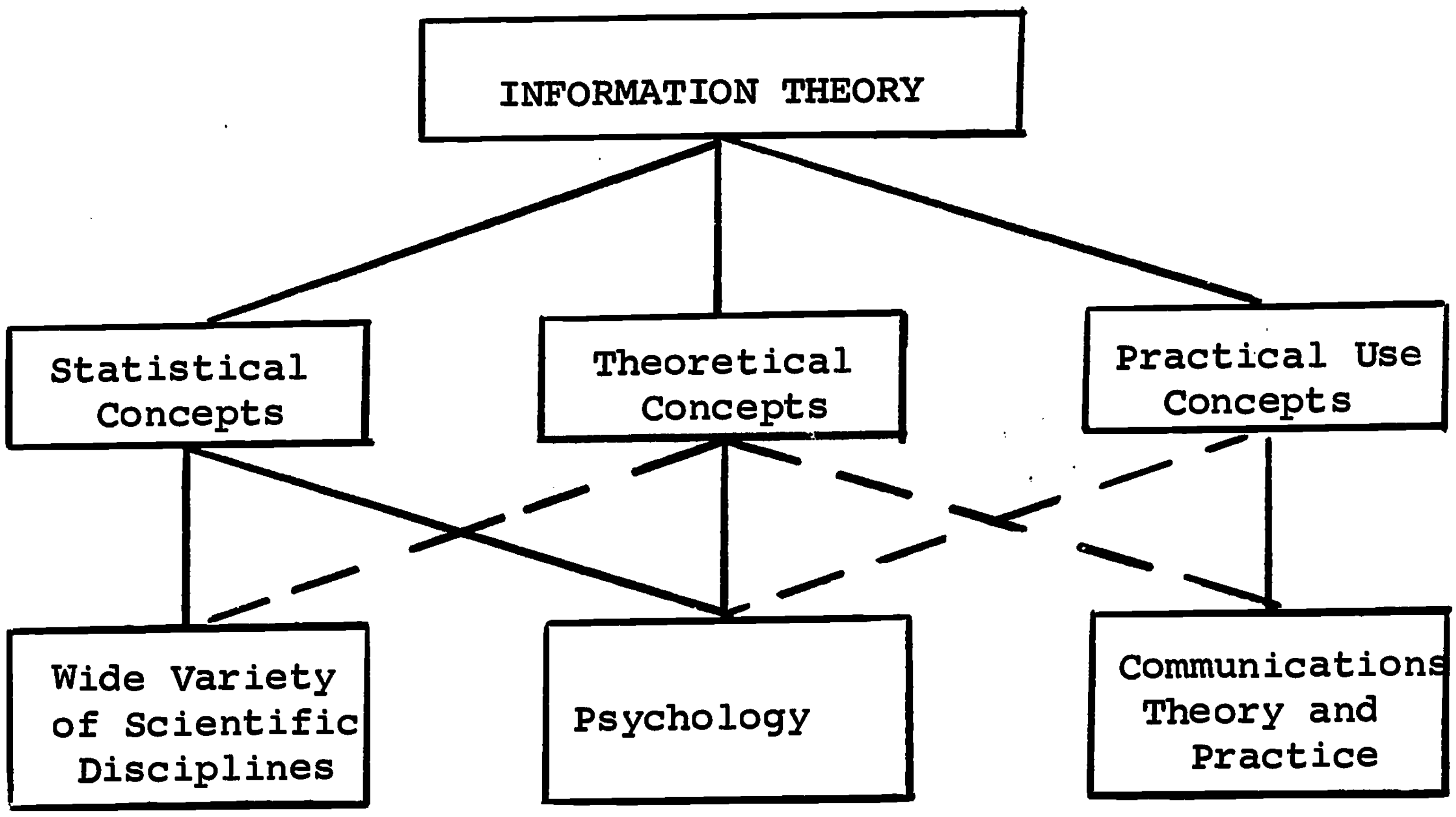

Fig. 2. A schematic representation of information theory and its application. The second or middle level represents the conceptual areas of the theory and the third or lower level of the diagram gives the scientific disciplines making most use of the three concepts. Solid lines represent primary use; broken lines secondary use.

A third area, and the one of particular interest in this study, has been the application of information theory to psychology. Attneave, analyzing the situation in 1959, said the relevance of information theory to psychology had been clearly demonstrated. Summing up the results, he said the theory did not provide a ready-made solution to all psychological problems, but employed with intelligence, flexibility, and critical insight it could have value both in the formulation of certain psychological problems and in the analysis of certain psychological data.[1] A bibliography prepared by Garner, which appears to be a reasonably complete listing of the published literature on the application of information theory to psychology through 1960, lists 276 items, and the work of 221 authors cited in the body of the book.[2]

Specifically, information theory, or an adaptation of it sometimes called psychological information theory, applies information-theory measures to phenomena within the purview of psychology and uses information-theory language to formulate laws or hypotheses with testable implications about behavior.[3]

Perhaps the most distinguishing feature between the theoretical and the practical approach to information theory useage (as defined in the model presented in Fig. 2) is that in the practical application there is concern for meaning (semantics) and the degree to which the received meaning affects conduct in the desired way, while in the theoretical application there is no such concern. As Miller puts it, only the amount of information is measured, with no specification as to content, value, truthfulness, exclusiveness, history, or purpose of information.[4]

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[1] Fred Attneave, Applications of Information Theory to Psychology (New York: Henry Holt and Co., 1959), pp. v-vi.

[2] Wendell R. Garner, Uncertainty and Structure as Psychological Concepts (New York: John Wiley and Sons, Inc., 1962).

[3] D. E. Berlyne, "Uncertainty and Conflict: A Point of Contact Between Information-theory and Behavior-theory Concepts," The Psychological Review, Vol. 64 (Nov., 1957), p. 329.

[4] George A. Miller, "What Is Information Measurement?" The American Psychologist, Vol. 8 (Jan., 1953), pp. 3-11.

The unifying or commonality feature that has enabled researchers to put the theory to wide use in both theoretical and practical situations is the model itself (Fig. 1). It is best to think of this model as a step-by-step process, consisting of essentially five parts:

(1) An information source produces a message or sequence of messages to be communicated to the receiving terminal.

(2) A transmitter operates on the message in some way to produce a signal suitable for transmission over the channel.

(3) The channel is the medium used to transmit the signal from transmitter to receiver.

(4) The receiver performs the inverse operation of that done by the transmitter, reconstructing the message from the signal.

(5) The destination is the person (or thing) for whom the message is intended.

If a communication system were operating perfectly, the received message would correspond perfectly to the original message. However, the system is not likely to be perfect. Shannon introduced the term noise to cover the many elements that may affect the message transmission. Noise may be regarded as any irrelevant signal arising within the system itself which may interfere with the message being transmitted in ways which mask the signal or confuse the message. The efficiency of a communication system may also be impaired by coding and decoding mistakes, and a system is limited with respect to the kind and amount of information which it can transmit.[1]

Information within the information-theory context is usually defined in terms of the reduction of uncertainty. The amount of information contained is related to the probability of predicting its occurrence. Mathematically stated, the amount of information

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[1] Jerry D. Tate, "Some Effects of Multidimensional Stimulus Information on Processing Time" (unpublished dissertation, Ohio State University, 1965), pp. 1-2.

contained in any given segment is equal to the logarithm to the base 2 of the number of alternatives which can occur in a given context.[1]

In its simplest form, the formula is: $I = \log_2 n$ when the probability of occurrence of all stimuli in the set is equal; n is the number of alternatives or probabilities, and $\log_2$ is the logarithm of n to the base 2. The unit most often used in the measurement of information and uncertainty is the bit, a contraction of binary digit. To illustrate, if a given set of stimuli contains eight equally likely alternatives, the amount of information or stimulus uncertainty contained in the set is 3 bits (log of 8 to the base 2 = 3).

As related to this study, Klemmer and Frick say, "Any situation involving perception may be considered in terms of the transmission of information. What is perceived may be described, not only by words and numbers related to the physical nature of the stimulus, but also in terms of an 'amount of information' measure."[2] They also state that the measure may be applied without difficulty to any situation in which one is willing to identify the stimulus and response classes and make some statements about their probability distribution.

The methodology of information theory has created a new interest by psychologists in the absolute judgment method of measuring stimulus response. Absolute judgment may be characterized as a type of judgment in which an observer is required to identify by a name, number, or value each member of a set of individually presented stimuli.[3]

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[1] Murray Aborn and Herbert Rubenstein, "Information Theory and Immediate Recall," Journal of Experimental Psychology, Vol. 44 (Oct., 1952), p. 260.

[2] E. T. Klemmer and F. C. Frick, "Assimilation of Information from Dot and Matrix Patterns," Journal of Experimental Psychology, Vol. 45 (Jan., 1953), p. 15.

[3] Charles W. Eriksen and Harold W. Hake, "Absolute Judgments As a Function of Stimulus Range and Number of Stimulus and Response Categories," Journal of Experimental Psychology, Vol. 49 (May, 1955), p. 323.

The objective is to determine how much information the observer obtains about which particular stimulus. There may be one (unidimensional) or more than one (multidimensional) stimulus dimensions to the objects being judged. The use of absolute judgments in the study of information input and output draws some measurable boundaries around the communication system under study, and generally does an acceptable job of preventing interference from outside influences. One of the major difficulties in studying complex information processing is the quantification of informational input and output. Absolute judgment provides such a system, although it does restrict the experimenter to rather simple problems and clues.

The Human as a Communication System

The similarity between an electronic transmission system and the human organism has led to the treatment of the latter as a communication or information processing system:

> Messages from the environment, in the form of external or internal stimuli, impinge upon the sense organs and are encoded into neural impulses. These neural impulses pass to the central nervous system (the channel of communication) where the decision process takes place; finally, the messages emerge as observable responses (decoded neural impulses). The adequacy of the messages in conveying information about the environment from which the stimuli arose (the source of the messages) depends on the extent to which the human transmitter makes discrete responses in a consistent manner to discrete stimuli.[1]

Miller considers the blood and lymph of the individual to be information-carrying channels, and he says there are two distinct common uses of the word _channel_. "The more restricted meaning includes only the flow rate for the information, without intervening subsystems of any sort (such as transducers, decoders, or encoders). The other, broader meaning includes such components together with the intervening flow rates."[2]

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[1] Tate, _op. cit._, p. 2.

[2] James G. Miller, "The Individual As an Information Processing System," in _Information Storage and Neural Control_, edited by William S. Fields and Walter Abbott (Springfield, Ill.: Charles C. Thomas, 1963), p. 303.

In this study the concern ranged from the presentation of stimuli through the organism until the messages emerged as observable responses. No effort was made to separate out the various subsystems of a human information processing system, although it should be noted that the various body organs involved are ones included earlier as being affected by the aging process.

Like an electronic communication system, the human system has limitations. It is subjected to noise interferences within and without the system. There are limitations on the sensitivity and ability to discriminate among stimuli, and the organism is restricted in the number of discrete responses that it can emit.[1]

When the human is considered as a communication system, certain concepts from information theory can be used to measure information processing capacity of the system. Said another way, it is possible to evaluate the capacity of the human organism as a transmitter of information.

Stated in the most simple fashion, information processing capacity is the ratio between the information received by or fed into the communication system (input) and the information that is transmitted through the system (output), measured in bits per stimulus or given time period. The output can never be greater than the input, and only in very unusual or elementary situations will the output ever equal the input.

Information available to the system can come from two sources: stimulus alternatives or source of messages, and response alternatives or destination of messages. The sum of the information in both these sources, considered separately, is the total amount of information available to the communications system. However, it should be noted that stimulus and response do not operate independently of each other. Rather, there is some correspondence between the stimulus and response alternatives--the response emitted will be determined in large part by which stimulus alternative has occurred.

A schematic representation of this situation, when messages are received from two related sources, has been developed by Miller[2] and can be shown as illustrated in Figure 3.

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[1] Tate, op. cit., p. 2.

[2] George A. Miller, "What Is Information Measurement?" pp. 6-7.

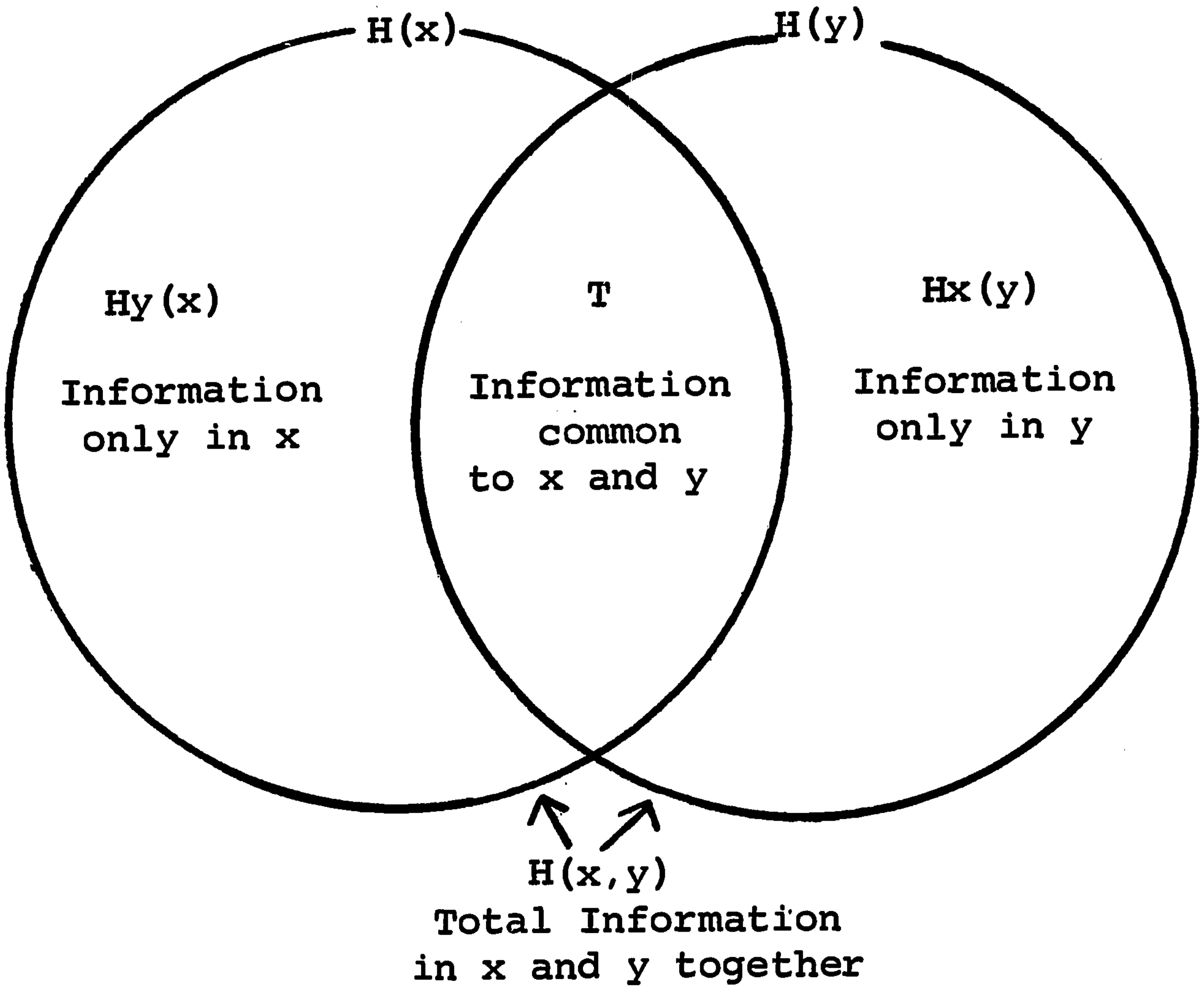

Fig. 3. Schematic representation of several quantities of information that are involved when messages are received from two related sources. (Miller, 1953.)

In this model x is the source that generates the input information and y is the source that generates the output information; y is the channel itself. Since x and y are related sources of information, the overlap or common information is what is transmitted. H(x) is the average amount of input information; H(y) is the average amount of output information. T is the average amount of transmitted information. H(x,y) is the total amount of information when both the input and the output are known. Therefore, H(x,y) includes the lost, the transmitted, and the added information. It can be determined by the following formula:

$$H(x,y) = Hy(x) + T + Hx(y)$$

Discrimination and Stimulus Complexity

In defining the absolute judgment method of stimulus response earlier it was stated that this is a type of judgment in which an observer is required to identify by a name, number, or value each member of a set of individually presented stimuli. In other words, the subject is required to discriminate between the stimuli within each set. Therefore, in the context of this study, discrimination refers to the ability of a subject to distinguish one item from the other items in a set of correlated stimuli.

Although there is some debate among psychologists as to just what type of discrimination is involved, the term "perceptual discrimination" is the one most often used to designate the type of judgments being investigated in this experiment.

It has been pointed out that as the human organism grows older it is faced with greater difficulty in reacting to and comprehending more complex situations or materials. As was indicated on page 2, one of the purposes of this research was to explore the relationship between age, information processing capacity, and complexity of the stimulus materials.

In this study stimulus complexity is defined as follows: In a single or unidimensional stimulus presentation, when the amount of uncertainty placed into an absolute judgment situation is increased finer discriminations are required. As finer discriminations are called for the situation increases in complexity. Also, where a multidimensional stimulus field is being used, there is less complexity in the situation for a given amount of stimulus uncertainty than there is in a unidimensional stimulus field. To illustrate, in a unidimensional stimulus presentation, a set of stimuli containing 16 alternatives is considered more complex than a similar presentation containing 15 alternatives. But a multidimensional stimulus presentation of a set of stimuli containing 16 alternatives is considered less complex than a related unidimensional set of stimuli also containing 16 alternatives.

It should be pointed out, however, that under most conditions investigated by psychologists the addition of a second or third stimulus increases the complexity of the total stimulus field.[1]

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[1] Robert S. Woodworth and Harold Schlosberg, Experimental Psychology (New York: Henry Holt and Co., 1954), pp. 16-39, 194-199.

Therefore, the addition of one or more correlated dimensions to a set of stimuli resulting in improved discrimination of the stimuli where absolute judgment is used is an exception to results ordinarily obtained in experiments with perceptual discrimination.[1]

Hypotheses Tested

A theoretical framework has been presented from which the following directional hypotheses were deduced:

1. As age increases, information processing capacity of the human organism will decrease when measured by a single or unidimensional visual stimulus.

2. As age increases, information processing capacity of the human organism will decrease when measured by a multidimensional visual stimulus.

3. At all ages, information processing capacity of the human organism will be greater when exposed to a multidimensional visual stimulus than when exposed to a unidimensional visual stimulus.

4. The decrease or loss of information processing capacity as related to age (Hypotheses 1 and 2) will be greater in more complex stimulus situations where finer discriminations are called for (Series A: Test 1 compared with Test 2, Test 2 compared with Test 3; Series B: Test 4 compared with Test 5).[2]

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[1] W. R. Garner and C. Douglas Creelman, "Effects of Redundancy and Duration on Absolute Judgments of Visual Stimuli," Journal of Experimental Psychology, Vol. 67 (Feb., 1964), p. 168.

[2] It should be noted that three hypotheses were also proposed concerning channel capacity, a special case of information processing capacity as defined on page 2. It was suggested that Tests 2 and 3 should approximate channel capacity of all age groups in the unidimensional stimulus situation. In the multidimensional stimulus situation it was anticipated that Test 5 would be close enough to channel capacity to offer a measurable interpretation of these hypotheses. There was evidence that channel capacity at all age levels was approached with these tests, but this evidence was not sufficient to permit conclusions in terms of the independent variable (Age) being tested. Therefore, all activity concerned with this concept, although considered an important part of the study, has been omitted from this report.

The rationale offered in support of these hypotheses is as follows:

Hypotheses 1 and 2 state that as a person grows older his information processing capacity will decrease. It has been demonstrated that a characteristic of the aging process is that the organism slows, not only in the observable acts in which he engages, but in the important internal bodily organs, including those that have been reported to be directly related to information processing ability. It is hypothesized that this slowing down will be reflected in a measurement of information processing capacity.

The measurements by which Hypothesis 1 will be tested are the slope and elevation of the lines representing Tests 1, 2, and 3. The hypothesis states that information processing capacity declines with age; therefore, each line will slope to the right and elevation will be less at the older-age end of the range.

The measurements by which Hypothesis 2 will be tested are the slope and elevation of the lines representing Tests 4 and 5. The hypothesis states that information processing capacity declines with age and each line will slope to the right and elevation will be less at the older-age end of the range.

Hypothesis 3 states that when the organism is exposed to a multidimensional visual stimulus, information processing capacity will be greater than when the exposure is to a single visual stimulus. Specifically, this hypothesis states that scores for Tests 4 and 5 will lie above the scores for Tests 1, 2, and 3 at all age groupings. Should scores on Tests 4 and 5 fall below either Test 1, 2, or 3 for any age group, the hypothesis would be automatically rejected without a statistical analysis.

Hypothesis 4 states that in addition to a lowering of the information processing capacity as age increases, there will also be a measurable difference or relationship between age and the amount of discrimination required with the various stimuli. Test 1 requires a size discrimination between 8 equally-likely alternatives while Test 2 requires discrimination between 13 alternatives and Test 3 between 20 equally-likely alternatives. Test 4 requires location of the placement of a dot in a grid pattern containing 16 possible locations, while Test 5 requires the location of a dot in a grid pattern containing 36 possible locations. It was hypothesized that the finer discriminations and more complex situations would work to the handicap of the older subjects.

Review of Related Research

As indicated earlier, the advent of information theory has stimulated considerable research that has used absolute judgment to measure information capacity of the human organism. Stimuli used have been auditory, taste, touch, and visual, presented as single and multidimensional stimuli. Articles by Miller, Alluisi, and Garner give good summaries of the studies using this technique.[1]

Auditory and Other Stimuli

The measurement of channel capacity using auditory stimuli has given results similar to those reported below for visual stimuli. Unidimensional auditory stimulations have resulted in the transmission of an average of around 2.5 bits/stimulus, slightly lower than the average for all visual stimuli. Similar results are reported where touch and taste were the variables being used as stimuli. Multidimensional auditory, touch, and taste stimulus presentations also give results similar to those reported here for visual stimuli.

Visual Stimuli

Table 1 summarizes the recorded studies that have been carried out with unidimensional and multidimensional visual stimuli. The similarity of results, in experiments conducted under a wide variety of conditions, indicates face validity of this method of measuring performance.

Based on information available, the subjects used in these studies were primarily college undergraduates enrolled in introductory psychology classes. With the exception of the 1953 Klemmer-Frick experiment, it appears that all testing was done in specially-equipped experimental laboratories. The Klemmer-Frick study was conducted in a classroom situation.

All studies have demonstrated that when exposed to a multidimensional stimulus, the channel capacity or information output is greater than it is with a single stimulus, but the information

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[1] George A. Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," Psychological Review, Vol. 63 (March, 1956), pp. 81-97; Earl A. Alluisi, "Conditions Affecting the Amount of Information in Absolute Judgments," Psychological Review, Vol. 64 (March, 1957), pp. 97-103; Garner, *op. cit.*

Table 1. Summary of research using absolute judgments and visual stimuli to measure information processing and channel capacity of the human organism

Experimenter	Date	Stimuli Used	Information Transmitted in Bits/ Stimulus
<u>Unidimensional Stimuli</u>			
[1]Hake and Garner	1951	Pointer position on line	3.25
[2]Eriksen and Hake	1955(a)	Size of gray squares	2.20
[3]Eriksen and Hake	1955(b)	Brightness	2.34
"	"	Size of colored squares	2.84
"	"	Hue (colored squares)	3.08
[4]Conover	1955	Hue (colored circles)	3.51
5 "	1959	Hue (colored circles)	3.50
[6]Chapanis and Halsey	1956	Hue (colored rectangles)	3.60
[7]Garner and Creelman	1964	Size of black squares	2.68
"	"	Hue (colored squares)	2.35
[8]Garner, <u>et al</u>.	1966	Size of dark squares	2.19
<u>Multidimensional Stimuli</u>			
[9]Klemmer and Frick	1953	Dots in grid pattern	4.40

Table 1 Continued

Experimenter	Date	Stimuli Used	Info. Trans.
[3]Eriksen and Hake	1955(b)	Size and hue	3.55
"	"	Size and brightness	2.98
"	"	Hue and brightness	3.76
"	"	Size-hue-brightness	4.11
[7]Garner and Creelman	1964	Size and hue	3.30

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[1] Harold W. Hake and W. R. Garner, "The Effect of Presenting Various Numbers of Discrete Steps on Scale Reading Accuracy," Journal of Experimental Psychology, Vol. 42 (Nov., 1951) p. 361.

[2] Eriksen and Hake, "Absolute Judgments . . .," p. 325.

[3] Charles W. Eriksen and Harold W. Hake, "Multidimensional Stimulus Differences and Accuracy of Discrimination," Journal of Experimental Psychology, Vol. 50 (Sept., 1955), p. 155.

[4] Donald W. Conover, "The Amount of Information in the Absolute Judgment of Munsell Hues" (unpublished dissertation, Ohio State University, 1955), reported in Earl A. Alluisi, "Conditions Affecting the Amount of Information in Absolute Judgments," Psychological Review, Vol. 64 (March, 1957), p. 99.

[5] Donald W. Conover, "The Amount of Information in the Absolute Judgment of Munsell Hues," USAF WADG Technical Note No. 58-262 (1959), reported in Garner, Uncertainty and Structure as Psychological Concepts, p. 72.

[6] A. Chapanis and R. M. Halsey, "Absolute Judgments of Spectrum Colors," Journal of Psychology, Vol. 42 (1956), p. 100.

[7] Garner and Creelman, "Effect of Redundancy and Duration on Absolute Judgments of Visual Stimuli," p. 170.

[8] W. R. Garner, George Kaplan and C. Douglas Creelman, "Effect of Stimulus Range, Duration, and Contrast on Absolute Judgments of Visual Size," Perceptual and Motor Skills, Vol. 22 (April, 1966), p. 644.

[9] Klemmer and Frick, "Assimilation of Information from Dot and Matrix Patterns," pp. 16-17.

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output is less than the combined possible output if the information content of the two stimuli were added. To illustrate, in the three tests by Eriksen and Hake in 1955 where the stimulus was brightness, size, or hue, the average information transmitted per stimulus was a mean of 2.75 bits; when two stimuli were combined the mean rose to 3.43 bits; when three stimuli were combined the mean was 4.11 bits.

Size of Squares and Dot Placement Tests

Of particular interest to this study is the literature relating to the two visual stimulus patterns used in this study--size of squares and dot location.

The first experiment using size of squares as the stimulus was carried out by Eriksen and Hake at The Johns Hopkins University and reported in 1955.[1] They were particularly concerned with the extent to which the number of absolutely discriminable stimulus categories could be affected by subjective anchoring effects associated with the range and density of the stimulus dimension and with the number of response categories available to subjects for expressing judgments.

Two size ranges were studied. In one test the size of the squares was spread over the range of 2-42 mm. square. In the second situation the size of the squares was doubled, ranging from 2 to 82 mm. The stimulus materials were squares cut from a dark gray paper and pasted in the center of 8 x 11-inch white cardboards.

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[1] Eriksen and Hake, "Absolute Judgments . . . ," pp. 323-332.

For both stimulus and response variables, 5, 11, and 21 categories were used, making a total of 18 treatment conditions. Subjects were given all the time they needed to make their responses.

Information transmitted ranged from a low of 1.47 bits where 21 stimuli were presented and only 5 responses were permitted, to a high of 2.23 bits in two situations--11 stimuli and 11 responses, and 11 stimuli and 21 responses. For all conditions where the number of stimuli presented equaled the number of responses permitted, an average of 2.08 bits of information per stimulus was transmitted.

A short time later the same two authors investigated the question of whether or not stimuli could be more accurately discriminated from one another if they differ on two or three dimensions than if they differ on a single dimension.[1] They used three single dimension stimuli--size of squares, hue, and brightness.

Combinations of these stimuli were made to form multidimensional stimulus situations (see Table 1).

In the size of squares test 20 alternatives were used, ranging in size from 1/2 inch to 2 1/2 inches, with a 1/8-inch dimension difference between each of the sizes. The squares were cut from dark gray paper and mounted in the center of white 3-inch cardboard squares. The average amount of information transmitted for the size test was 2.84 bits.

No further work with size of squares showed up in the literature until the mid-1960's, when the subject was reopened by Garner and his associates at Johns Hopkins. In a 1964 report he and Creelman used three different sets of 20 squares, presented visually at one of two durations.[2] One set of squares varied in size alone, another in hue alone, and a third set varied in both size and hue, with the two dimensions correlated.

The squares ranged from 1/4 inch to 5 inches on a side, varying in 1/4-inch steps. They were cut from black Munsell paper and mounted on white 10-inch square cards.

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[1] Eriksen and Hake, "Multidimensional Stimulus . . .," pp. 153-160.

[2] Garner and Creelman, op. cit., pp. 168-172.

An elaborate reproduction box and projector apparatus was used in the experiment, including a timer for duration control. Two durations of stimulus exposure were used--1/25 second and 1/10 second. The stimuli were presented in random order approximately one every 10 seconds. A warning bell rang 3 seconds before each presentation.

For the judgment of hue alone, and for the combination of hue and size, there were differences in information transmission (Table 1). But for the judgments of size alone, the average was 2.69 bits with a duration of 1/10 second and 2.68 bits with the 1/25-second duration.

Garner and his colleagues followed up this study with another two years later.[1] The experimental equipment was the same as listed above, but three ranges of size and two exposure durations were used. Twenty stimulus sizes were used per set: Small, from .71 to 1.85 inches on a side in steps of .06 inches, giving a total range of 1.14 inches; Medium, from .485 to 2.1 inches in steps of .085 inches, giving a total range of 1.615 inches; and Large, from .17 to 2.45 inches, in steps of .12 inches, giving a total range of 2.28 inches. Duration time was .020 seconds and .040 seconds.

Stimuli were presented at the rate of approximately one every 7.5 seconds, with a 3-second warning bell.

The amount of information transmitted ranged from 1.88 to 2.50 bits per stimulus. In all cases the amount of information transmitted increased as the size range increased. Also, for each range there was greater information transmission with the longer duration.

There is only one reported study using the placement of a dot in a grid pattern, which, incidentally, is the only reported study of relevance here that was conducted in a group situation and not with subjects performing individually in a laboratory setting.[2]

The visual stimuli consisted of one or more white dots inside the white outline of a square on a black background. Matrix orders ranged from 3 x 3 to 20 x 20, with the smallest having 9 cells and the largest 400. The number of dots in an individual matrix ranged from 1 to 4.

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[1] Garner, Kaplan, and Creelman, op. cit., pp. 635-644

[2] Klemmer and Frick, op. cit., pp. 15-19.

The stimuli were photographed on 2 x 2 slides and projected on a screen from a slide projector fitted with a .03-second shutter. Fifteen to 25 subjects were run simultaneously in a semi-darkened room.

The amount of information transmitted ranged from 3.2 bits per stimulus (maximum possible with the 3 x 3 matrix) to approximately 4.4 bits under more complex situations.

Age As a Variable

In the studies reviewed, in only two was age of subjects mentioned. In a study using an auditory stimulus it was reported that subjects were in the age range 20-30, and the 1955 hue study by Conover contained subjects between 15 and 64, but age was not one of the variables measured in either study.

Two studies of aging have used information measurement (but not absolute judgment) in relation to age, both concerned with performance time as well as with information channel capacity. Welford obtained times for dotting alternately on two targets either one inch or two inches in diameter and either one foot or two feet between centers. Using subjects ranging from around 20 through their 60's, he found that the rate of information transfer declined with age (from approximately 12 bits per second for those in their 20's to seven bits per second for the 60-year-olds).[1]

An experiment by Crossman and Szafran showed a somewhat different pattern. Comparing a group of subjects averaging 20-25 with another group averaging 70-80 at a card sorting task, they found that the younger group had an information rate of 3.07 bits per second compared to a rate of 2.75 bits per second for the older group. However, a reanalysis of their data revealed that most of this difference appeared in what might be called the practice period, or what the authors called the initial rate. The incremental rate (performance after the practice session) showed no statistically-significant difference in performance related to age.[2]

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[1] Alan T. Welford, Aging and Human Skill (Oxford, England: Oxford University Press, 1958), pp. 98-100.

[2] E. R. F. W. Crossman and J. Szafran, "Changes with Age in the Speed of Information Intake and Discrimination," in Experimentelle Alternsforschung (Experimental Research on Aging), edited by Herausgegeben von (Basel, Switzerland: Birkhauser Verlag, 1956), pp. 129-132.

Methodology and Procedures

Selection of Testing Instruments

It is apparent from the literature that size of squares has been an effective stimulus where subjects are asked to make absolute judgments. Except under the very rigid durations used by Garner and his associates in their 1966 tests, duration time has not been a critical factor in size of squares judgments, thus avoiding the limitation of older subjects not being able to react quite as fast or "see" an object as rapidly as younger subjects. The literature reviewed did not reveal a situation in which this stimulus had been presented in a group situation. However, it seemed reasonable to assume that this stimulus could be projected on a screen to be judged before a group. It is true that in several studies it had been shown that there existed a relationship between size range and ability of individuals to discriminate between the various alternatives, but size of the stimulus would be similar for all age groups, and it was assumed that the participants would randomly seat themselves in the testing station in relation to distance from the screen.

Selecting the multidimensional stimulus was considerably more difficult. It is readily apparent from Table 1 that the most popular multidimensional stimulus used in tests of this kind in recent years has been a combination of shape and color (hue and brightness). However, it is quite obvious that with the dramatic decline in color discrimination ability as the adult ages, color could not be used in the presentation.

Klemmer and Frick had successfully used subjects in groups with the stimuli projected on a screen. But it was realized that duration exposure time in such a test would be critical in that the time must be long enough for the "slower eyes" to see the stimulus but short enough that the "faster eyes" would not have time to determine the location of the dot by analysis of the two dimensions on which the stimulus was being judged, i.e., "that dot is two spaces over from the left and two down from the top." However, in view of the risks involved, and as almost a practical necessity, the dot and grid pattern developed by Klemmer and Frick for their 1953 study was selected.

Subject Selection

It was felt that there were several factors (physiological, motivational, etc.) that must be given recognition in selecting subjects for this experiment.

First, it was assumed that subjects engaged in learning situations would be more likely to exhibit a level of motivation that would lead them to participate in the testing situation with a high level of efficiency.

Second, it was felt that subjects in an occupation such as teaching, which requires extensive eye use and provides an income usually sufficient to meet a reasonably high level of health needs, would likely be able to perform satisfactorily with poor eyesight not being a particular handicap. At least the probability of having corrected any visual difficulty would be greater for such a group. The projection of visual images on a screen in a semi-darkened room would not be new to them.

Third, it was necessary to get a group together at one time with the desired age range and in a number that would permit detailed statistical analysis of the entire group and sub-groups.

To meet these requirements, a group of teachers with a wide age range and in a learning situation over an extended period of time was selected. The participants of the Southeast Regional Teacher Training Institute, held on The Florida State University campus in July, 1967, ranged in age from the early 20's through the middle 60's. The approximately 100 teachers and teacher-trainers, representing six Southeastern states in the federally-sponsored program, were about equally divided by sex and between white and Negro races.

The Institute participants were randomly placed into five sub-groups (workgroups) before their arrival on the FSU campus. The Institute Director assigned four of these sub-groups (approximately 80 subjects) for participation in the study.

Stimulus Development

Within the structural limitations of this study, it was possible to present five sets of stimuli or tests to the four test groups. The following block design was selected:

Group 1: Tests 1, 2, 4
Group 2: Tests 1, 2, 5
Group 3: Tests 1, 3, 4
Group 4: Tests 1, 3, 5

The following sets or tests were selected: 1, 2, and 3 (Series A) with size of squares as the stimulus; 4 and 5 (Series B) with the dot and grid pattern.

Series A

Test 1: Size range of 8, maximum information in test, 3.0 bits.

Test 2: Size range of 13, maximum information in test, 3.70 bits.

Test 3: Size range of 20, maximum information in test, 4.32 bits.

Series B

Test 4: 4 x 4 matrix, maximum information in test, 4.0 bits.

Test 5: 6 x 6 matrix, maximum information in test, 5.17 bits.

Two requirements were established for the selection of amount of stimulus uncertainty in the tests: (A) The first test in each series (Tests 1 and 4) should be at a fairly simple level at which all respondents could be expected to make near-perfect discriminations, including those at the older end of the age range should it develop that subjects in the older age groups had real difficulty in making judgments of the kind called for in this experiment; (B) The remaining test(s) in each series (Tests 2, 3, and 5) should be at a level that would approximate channel capacity.

In Test Series A, the squares were cut from black posterboard. The largest size in each set was approximately 5 inches, and the smallest was the size of the largest divided by the number of stimuli in the set. In Test 1 the squares ranged from 5/8 inch to 5 inches on a side, varying in 5/8-inch steps; in Test 2 squares ranged from 3/8 inch to 4 7/8 inches on a side, varying in 3/8-inch steps; in Test 3 the squares ranged from 1/4 inch to 5 inches on a side, varying in 1/4-inch steps (the same size as used in the 1964 Garner test). In Tests 4 and 5 the grid pattern of the matrix was made up of 1-inch squares, with the dot approximately 3/8 inch in diameter.

To produce the 2 x 2 slides used to present the stimuli, a single sheet of white posterboard served as the background for Test Series A, with the black squares placed on this background one at a time for photographing. In Tests 4 and 5, the grid pattern drawn on a white posterboard was used as the background, with the black dot moved from square to square.

Pretesting

Fourteen subjects, students and faculty at Florida State University, were used in pretesting the testing instruments. The age range of the participants was from 26 to 49, with a mean age of 38.

Means for the five tests (information transmitted in bits/stimulus) were as follows:

Test	Score
1	2.04
2	2.38
3	2.46
4	2.72
5	3.90

These scores were in line with scores from previous tests of this nature, as described in the previous section, "Review of Literature."

Data Collection

The subjects were available to the experimenter in groups for a two-hour period during the Institute. The experimental activity was fitted into their schedule of tours and other workgroup participation during this time.

The testing station was a room approximately 12 x 25 feet in size. The amount of light in the room was adjusted so the room would be dark enough to see the stimuli projected on the screen but light enough so response sheets could be easily seen.

The projector, a Kodak Carousel 800, was placed at a height of approximately 5 feet, so the line of projection to the screen would be on the level to avoid keystoning or other distortion. The screen was 40 x 40 inches with a dull finish. An Ilex tachistoscope for controlling duration time was mounted on a standard 5-inch lens. A timer on the projector controlled the time between stimulus presentations. Duration time was 1/10-second with 8 seconds between presentations.

Distance from projector to screen was approximately 18 feet. When projected on the screen the largest image in Test Series A was 27 inches. In Test 4 the matrix measured 16 inches; in Test 5 it measured 24 inches.

In Test Series A response was by number with the smallest square in each test as Number 1. In Test Series B the subjects responded by indicating location of the dot by either check, cross mark, or dot on the preprinted response forms. (See Appendix A for sample response forms.)

As the participants came into the testing station they were told that they would be making judgments of some images flashed on the screen, and they should select a seat they thought would be most comfortable to them. This seat selection took place until most of the seats were filled.

The training sessions for Tests 1, 2, and 3 were started by showing the subjects a chart which gave the relative sizes, accompanied by an explanation of the response system (use of a number to indicate size). Then they were shown all stimuli in the set, going from smallest to largest, followed by a reversal of the procedure and going through the set from largest to smallest. After questions and answers as necessary, the final training procedure was to again go through the set, starting with the smallest square.

The training sessions for Tests 4 and 5 were simply an explanation of the judgments that were to be made, an explanation of the response sheets and how they were to respond, and viewing the set of stimuli making up the test.

All groups were first exposed to Test 1, then the other Series A test, followed by the Series B test.

In Tests 1 and 2 duplicate sets of slides were used; in Tests 3, 4, and 5 only one set was used. Purpose of the duplicate sets for the two tests with the smallest number of alternatives was to prevent subjects from learning the sequence of presentation or random order of the stimuli.

The experimenter gave a warning signal or cue approximately 2 seconds before each image was flashed on the screen.

There were five trials or replications of each test. Explanation and training sessions ran approximately 20 minutes, with the actual testing situation ranging from 60 to 90 minutes, depending on the tests to which they were exposed. The number of responses per test were as follows: Test 1, 40 responses; Test 2, 65 responses; Test 3, 100 responses; Test 4, 80 responses, and Test 5, 180 responses. Therefore, the total number of responses per subject ranged from 185 for Test Group 1 to 320 for Test Group 4.

Statistical Analysis

The statistical problem was to determine the significance of the slopes of the lines for the five tests, and to make certain determinations about the elevation of the lines representing the scores on the five tests.

First, it was necessary to determine a score for each individual on each test. Several statistical techniques from information theory, outlined by Garner and Hake[1] and McGill,[2] were available for this purpose, each involving the construction of a matrix or contingency table to determine the individual score, in bits (the most common measurement of information transmission). The situation in this experiment was that input and output were correlated, but the successive signals or stimuli presented were independent. The model selected for analysis has been described by McGill.[3]

> Let us consider a communication channel and its input and output. Transmitted information measures the amount of association between the input and output of the channel. If input and output are perfectly correlated, all the input is transmitted. On the other hand, if input and output are independent, no information is transmitted. Naturally most cases of information transmission are found between these extremes. There is some uncertainty at the receiver about what was sent. Some information is transmitted and some does not get through.

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[1] W. R. Garner and Harold W. Hake, "The Amount of Information in Absolute Judgments," Psychological Review, Vol. 58 (Nov., 1951), pp. 446-459.

[2] William J. McGill, "Multivariate Information Transmission," Psychometrika, Vol. 19 (June, 1954), pp. 97-116.

[3] Ibid., pp. 97-98.

We are interested not in what the transmitted information is, but in the amount of information transmitted. Suppose we have a discrete input variable, x, and a discrete output variable, y. Since x is discrete, it takes on values or signals $k = 1,2,3, \ldots, X$ with probabilities indicated by $p(k)$. Similarly, y assumes values $m = 1,2,3, \ldots, Y$ with probabilities $p(m)$. If it happens that k is sent and m is received, we can speak of the joint input-output event (k,m). This joint event has probability $p(k,m)$. The rules governing the selection of signals at either end of the channel must be constructed so that

$$\sum_{k=1}^{k=X} p(k) = \sum_{m=1}^{m=Y} p(m) = \sum_{k,m} p(k,m) = 1$$

Under these conditions, assuming successive signals are independent, the amount of information transmitted in "bits" per signal is defined as

$$T(x;y) = H(x) + H(y) - H(x,y),$$

where

$$H(x) = - \sum_{k} p(k) \log_2 p(k)$$

$$H(y) = - \sum_{m} p(m) \log_2 p(m)$$

$$H(x,y) = - \sum_{k,m} p(k,m) \log_2 p(k,m)$$

One "bit" is equal to $-\log_2 (1/2)$ and represents the information conveyed by a choice between two equally probable alternatives.

If there is a relation between x and y, $H(x) + H(y) > H(x,y)$ and the size of the inequality is just $T(x;y)$. On the other hand, if x and y are independent, $H(x,y) = H(x) + H(y)$ and $T(x;y)$ is zero. It can be shown that $T(x;y)$ is never negative.

In the matrices used to determine individual test scores (matrices used in Tests 1 and 2 are shown in Appendix B), the columns represented the stimulus uncertainty or input variable x and the rows represented response uncertainty or output variable y. The subject's response to each stimulus was recorded in the matrix in the proper column and row. For example, in Test 1, stimulus size 5 was presented to a subject five times. Suppose he responded correctly (5) three times, once he responded 4, and once 6. On the matrix for this subject on Test 1 in the column headed 5 there would appear the tally 1 in row 4, the tally 3 in row 5, and the tally 1 in row 6. If the subject responded to all stimuli there would be five responses in each column on the matrix, and the stimulus uncertainty in the test would be $\log_2 n$, summed, or the log to the base 2 of the number of alternatives in the stimulus set or test, in the case of Test 1, $\log_2 8 = 3$ ($H(x)$ in the above model).

The sums of the rows were then tabulated, and these sums multiplied by a consonant or weight which had been developed from a table giving values of $\log_2 n$ and $-p \log_2 p$.[1] (These values vary for each test and are based upon the probability of occurrence of a given stimulus.) The summing of the resultant values for each row represented the response uncertainty in the test ($H(y)$ in the above model). These two values were then added to give the maximum uncertainty (U_{max}) in the test.

To determine the amount of "joint" uncertainty or uncertainty common to both stimulus and response, the individual cells containing a common number of responses were summed (say, all cells containing 1 response). These frequencies were then multiplied by the same set of consonants mentioned in the paragraph above. This amount of joint uncertainty ($H(x,y)$ in the model above) was then subtracted from the maximum uncertainty and the result was the amount of information transmitted, in bits, and the score for each individual test situation.

In Hypotheses 1 and 2, the following null and alternate statistical hypotheses were tested:

$$H_o\colon\ r = 0$$

$$H_1\colon\ r < 0$$

$$H_2\colon\ r > 0$$

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[1] Garner, <u>op. cit</u>., p. 345.

In Hypothesis 4, the following null and alternate hypotheses were tested:

$$H_o: B_1 - B_2 = 0$$

$$H_1: B_1 > B_2$$

$$H_2: B_1 < B_2$$

In Hypotheses 1 and 2, the standard F-test as applied to regression analysis was used:

$$F = \frac{\text{Variation due to regression mean squares}}{\text{Variation deviation about regression mean squares}}$$

In testing Hypothesis 4, a special t-test was used:[1]

$$t = \frac{(b_1 - b_2) - (B_1 - B_2)}{\sqrt{s^2 \left[\frac{1}{SS_{x1}} + \frac{1}{SS_{x2}}\right]}}$$

Scores and other data available on each subject were coded, punched on IBM cards, and processed on the CDC 6400 in the Computing Center at Florida State University. A standardized program (BMDO3R: Multiple Regression with Case Combinations), version of August 13, 1964, developed by the Health Sciences Computing Facility, UCLA, FSU Computing Center Version, December, 1966,[2] was used.

Output for this program used in the analysis included the F-values which were used to determine if the correlation for each test was statistically significant (Hypotheses 1 and 2), and regression coefficients and sum of squares needed for determining significance of Hypothesis 4.

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[1] Jerome C. R. Li, Statistical Inference I (Ann Arbor, Mich.: Edwards Brothers, Inc., 1964), p. 400.

[2] W. J. Dixon (ed.), BMD Biomedical Computer Programs (Los Angeles: University of California, revised 1965), pp. 258-269.

A 2x2x2x2 factorial analysis of variance was developed to determine influences of several possible intervening variables (test, age, sex, and eye condition).

Further analysis included a comparison of scores and location of subjects in the testing room, and a tabulation of number of absolutely-correct judgments to determine if there was evidence of practice effect over the five replications of Test 1, or fatigue effects over the five replications of Tests 3 and 5.

To make the analysis of data as useful as possible, three levels of statistical significance (.01, .025, and .05) were reported, but the .95 confidence interval was used as the criterion for acceptance or rejection of the null hypotheses.

Group Comparisons

The response sheets were put together in tablet form, appropriate to each group. The cover sheet was used as a questionnaire to collect data on individual and group characteristics important in the study (Appendix A). These comparisons are shown in Table 2. It should be pointed out that eye condition reflected answers to five questions that were answered by each respondent, and then coded into the three categories shown in Table 2.

If the subject rated his eyesight as "good" or "average," and responded "no" in the remaining questions, he was considered to have good eyesight and "no eye problems." If he responded "average" or "poor" on eye condition and indicated either permanent or temporary eye difficulty ("yes" on last 2 questions), he was considered to have poor eyesight and "some eye problems." If he indicated "poor" eye condition, regardless of response on the remaining questions, he was also considered to have "some eye problems." If the response was "good" or "average" on eye condition, but the response was "yes" on the questions concerning a feeling of a need for glasses or glasses replacement, the subject was placed in the "possible eye problems" category in Table 2.

Table 2. A comparison of the four test groups used in the experiment

	Groups				
Classification	1	2	3	4	Totals
Number subjects	19	18	17	20	74
Age					
20-29	2	2	1	2	7
30-39	4	7	5	12	28
40-49	5	4	4	1	14
50-59	5	3	3	5	16
60-69	3	2	4	0	9
Mean age	45.2	41.2	46.9	40.5	43.5
Sex					
Male	6	10	11	10	37
Female	13	8	6	10	37
Amount of Schooling					
High school	0	0	0	0	0
1-2 years college	0	0	0	1	1
3-4 years college	0	0	1	0	1
College graduate	2	3	4	1	10
Graduate work	17	15	12	18	62
Eye Condition					
No eye problems	8	12	11	9	40
Some eye problems	4	3	3	1	11
Possible eye problems	7	3	3	10	23

Control of Intervening Variables

In this study eye condition was of particular concern. Should there be a decline in ability with an increase of age, as predicted, it was important to know if this might have come about because of poor eye condition on the part of the older subjects.

Although not expected, there could be education and sex-related differences. For example, a decline in performance as age increased could be attributed to a greater decline on the part of the aged of a particular sex, or the better educated might score higher.

The physical arrangement of the testing station dictated that all subjects could not be in a similar location in the testing station. It was important to know if the location influenced the results.

Then there was the possibility that interactions between these variables might bring about results not caused by the independent variable alone.

To determine possible influences of these variables and interaction between variables, a 2x2x2x2 factorial analysis of variance was developed using scores from Tests 2 and 3 which contained scores of all subjects but with a subject participating in only one test (independent data). The following model was used:

Individual score = Grand means + Test level + Age +
Sex + Eye condition + Error +
Interactions

Fifteen variables or combinations of variables were tested for effects. The analysis revealed two areas of significance--test and sex. Scores were higher in Test 3 than in Test 2, and the males outperformed the females at all age levels.

Other analyses revealed no advantage to any subjects because of testing room location, and no significant variations between replications that would indicate practice or fatigue effects.

Therefore, it was concluded that the differences in performance, reported and analyzed in detail in the following two sections, could be attributed to the influence of the independent variable, age.

Findings

Basic Analysis

The basic analysis of the experiment was performed by using the standard computer program BMDO3R and was designed to determine the significance of the relationship between age and information processing capacity.

As shown in Table 3 and Figures 4 and 5, and as predicted, there was some decline in information processing capacity as age of the subjects increased. In Tests 1, 2, and 4 this decline was statistically significant; in Tests 3 and 5 it was not.

Table 3. Statistical analysis of five tests used in the experiment to determine significance of relationship between age and information processing capacity

Test	Sample Size	Test Mean	Correlation Coefficient*	F-value	df	Level of Sig.
1	71	1.88	- .35	9.73	70	.01
2	37	2.24	- .42	7.40	36	.025
3	37	2.50	- .10	0.35	36	NS**
4	36	3.77	- .46	9.17	35	.01
5	38	4.33	- .17	1.06	37	NS**

*The linear correlation between age and test scores, with the negative sign indicating a decline in performance as age increases.

**At .05 level.

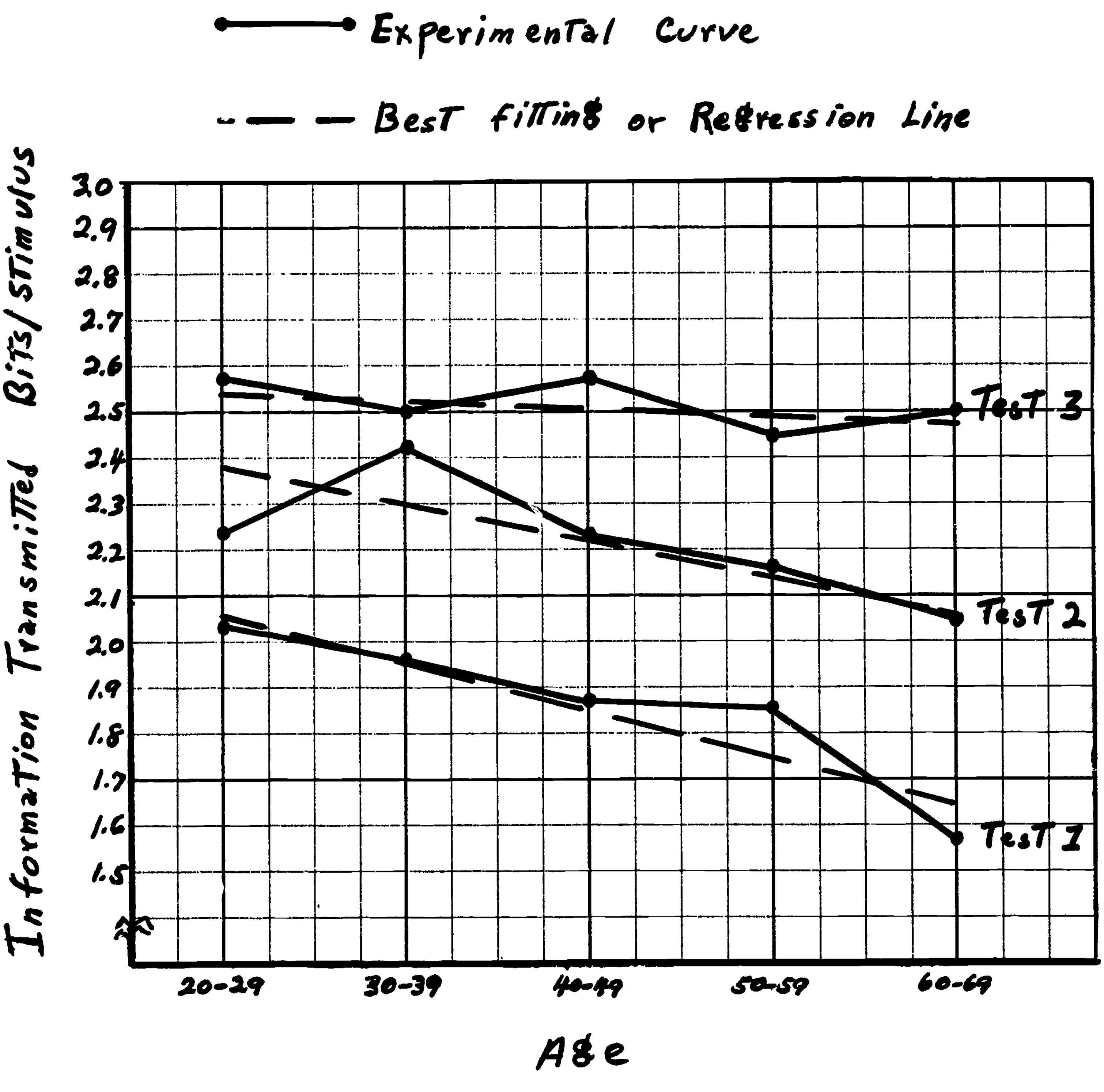

Fig. 4. Information transmitted scores by 10-year age grouping for the Series A tests using unidimensional stimuli.

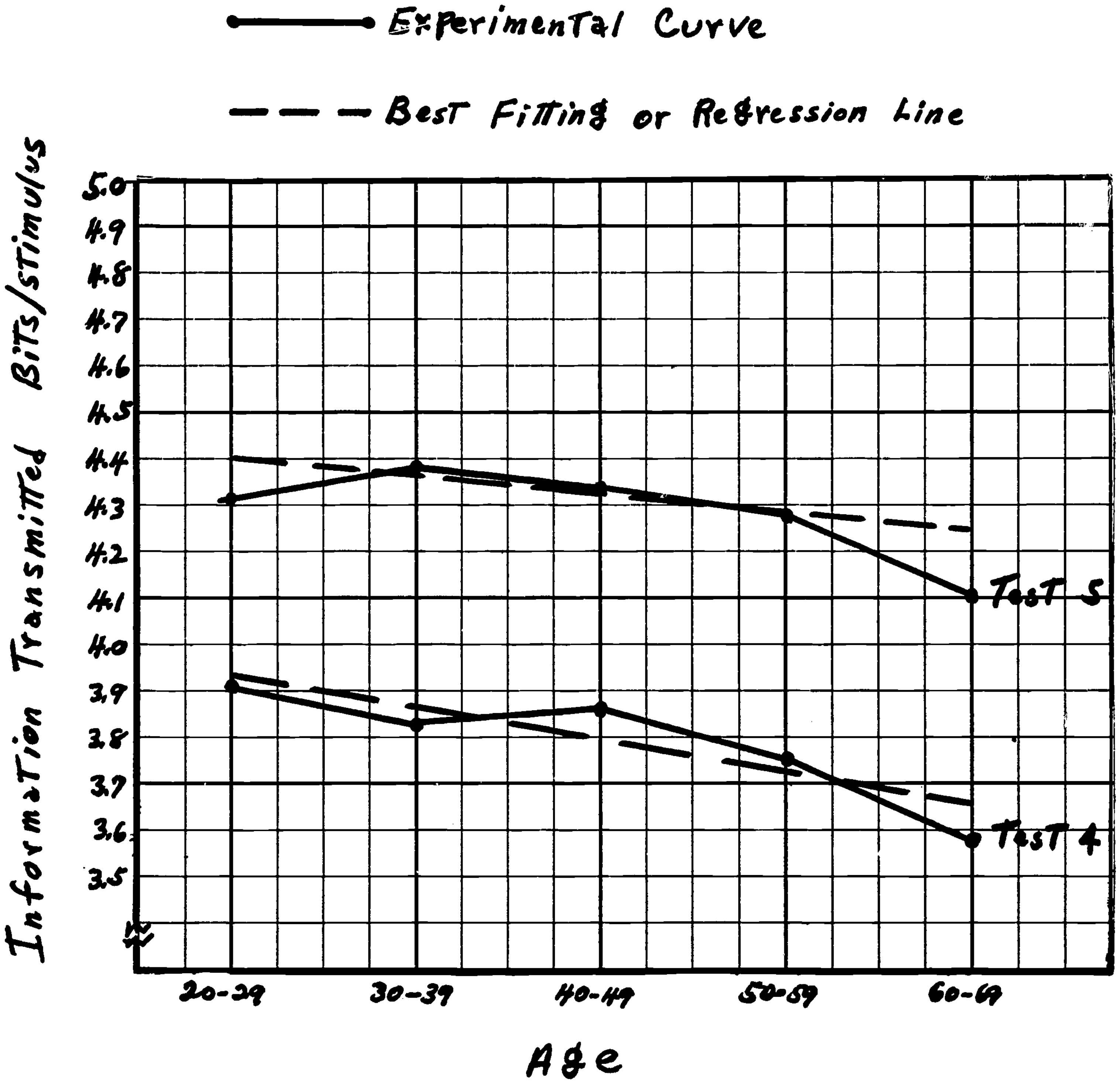

Fig. 5. Information transmitted scores by 10-year age grouping for the Series B tests using multidimensional stimuli.

Test of Hypotheses

Table 3 and Figures 4 and 5 provided the information used in testing Hypotheses 1 and 2. Both were concerned with information processing capacity, and the following statistical hypotheses were established:

H_0: $r = 0$; H_1: $r < 0$; H_2: $r > 0$.

Hypothesis 1 stated that as age increased information processing capacity of the human organism would decrease when measured by a single or unidimensional visual stimulus. Stimulus Series A, containing Tests 1, 2, and 3, provided data for the testing of this hypothesis. As shown in Table 3, in Test 1 the correlation of -.35 was significant at the .01 level. In Test 2 the correlation of -.42 was significant at the .025 level. The result of Test 3, with a correlation of -.10, although not significant at the .05 level, was in the predicted direction. Therefore, the null hypothesis of $r = 0$ was rejected, and alternate hypothesis 1 ($r < 0$) was sustained. The directional hypothesis, which stated that as age increased information processing capacity would decrease, was therefore accepted.

Hypothesis 2 stated that as age increased information processing capacity would decrease when measured by a multidimensional visual stimulus. Stimulus Series B, containing Tests 4 and 5, provided data for the testing of this hypothesis. As shown in Table 3, in Test 4 the correlation of -.46 was significant at the .01 level. The result of Test 5, with a correlation of -.17, although not significant at the .05 level, was in the predicted direction. Therefore, the null hypothesis of $r = 0$ was rejected, and alternate hypothesis 1 ($r < 0$) was sustained. The directional hypothesis, which stated that as age increased information processing capacity would decrease, was therefore accepted.

It might be added that on Tests 1 and 4 the attained F-value was considerably larger than needed for significance at the .01 level, while the F-value of Test 2 came very close to the F-value needed for significance at the .01 level. On the other hand, the F-values obtained on Tests 3 and 5 did not come close to those required for significance at the .05 level.

Although the number of tests used in this experiment was quite limited and different subjects were used in the tests that would be compared for the determination of channel capacity, it was anticipated, as stated earlier, that an approximation of channel capacity would be possible. However, the instruments used in the experiment did not provide sufficient data to make this determination.

A number of tests, where comparisons between unidimensional and multidimensional stimuli had been made, showed conclusively that the human organism acting as a communication system could process more information if the judgments could be based on more than one dimension. This situation existed whether or not information processing capacity or channel capacity was used as the criterion or dependent measure. However, all subjects had been college age.

Hypothesis 3 in this experiment stated that the ability to transmit information would be greater in the multidimensional stimulus situation at all age levels. The data in Table 4 and Figure 6 show that indeed it is. As shown in Figure 6, not only did the line for the multidimensional stimulus (Test 4) lie above the unidimensional stimulus (Test 3) at all age levels, but it was far above the lower line.

Table 4. A comparison of scores and percentage of uncertainty reduced in a unidimensional stimulus test and a multidimensional stimulus test with about equal stimulus uncertainty

		Age Groups				
Test	Item	20-29	30-39	40-49	50-59	60-69
3	Mean Score	2.58	2.50	2.57	2.44	2.50
	Percentage	59.7	57.9	59.5	56.7	57.9
4	Mean Score	3.91	3.82	3.84	3.75	3.59
	Percentage	97.8	95.5	96.0	93.8	89.8

Table 4 shows the mean scores for each age group on each test, and also the percentage of the maximum scores possible that was obtained for each age group, based on these means. For example, Test 3 contained an input of 4.32 bits of information. The 20-29 age group had a mean score of 2.58 on this test, which was 59.7 per cent of the maximum score that could have been made on the test. In comparison, the same age group had a mean score of 3.91 on Test 4, or 97.8 per cent of the maximum score of 4.0 that could have been made on this test. At all age levels there was a higher mean score and a higher percentage score. Therefore, the directional Hypothesis 3 was accepted.

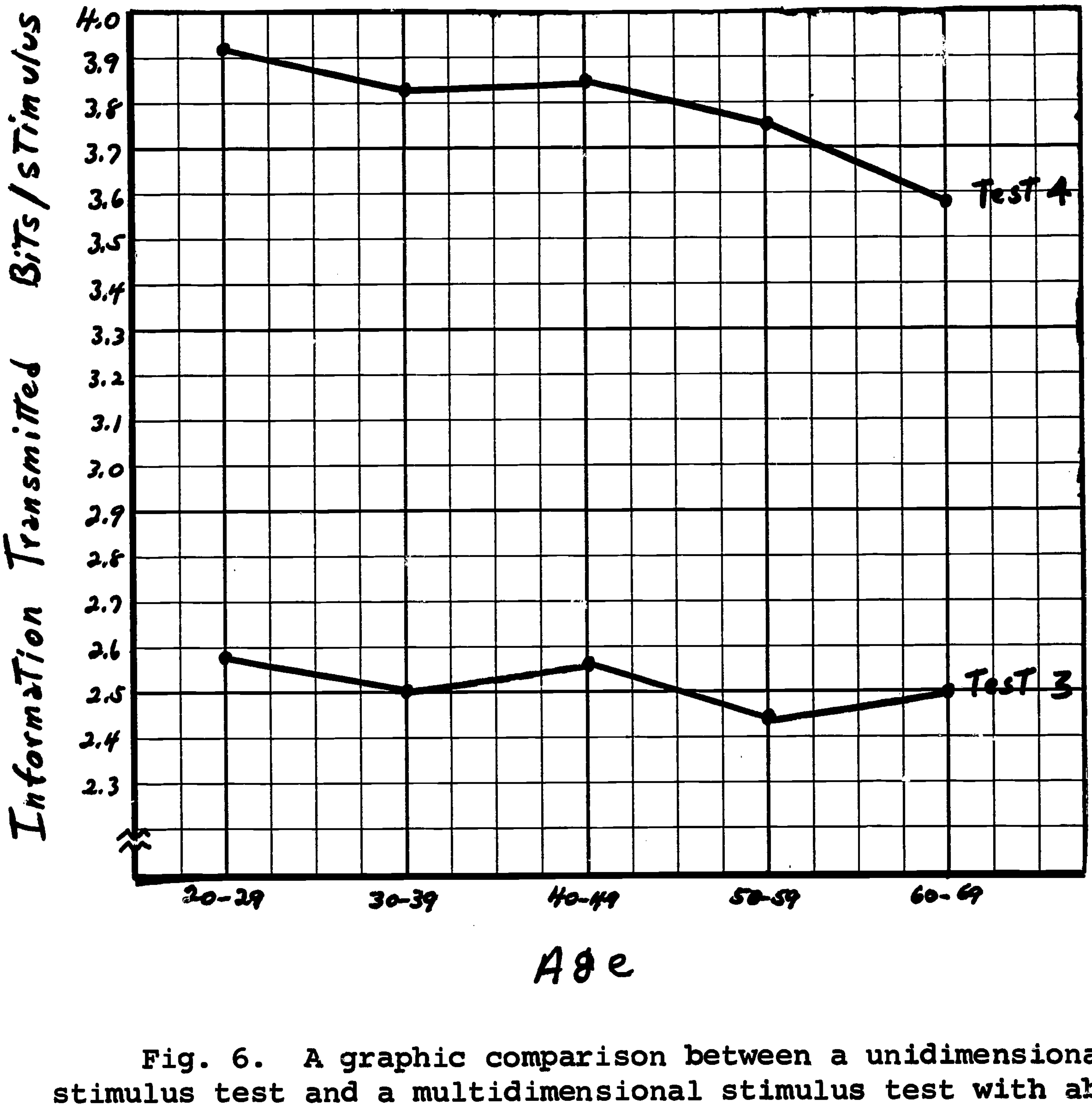

Fig. 6. A graphic comparison between a unidimensional stimulus test and a multidimensional stimulus test with about equal stimulus uncertainty.

Hypothesis 4 was concerned with the difference in slope of the lines representing the different tests. The directional hypothesis stated that the decrease or loss of information processing capacity as related to age would be greater in more complex stimulus situations where finer discriminations were called for (Test 1 compared with Test 2; Test 2 compared with Test 3; Test 4 compared with Test 5). Statistically the null hypothesis $B_1 - B_2 = 0$ was tested using a special t-test.[1] The results of this analysis are shown in Table 5.

Table 5. Scores from t-test used to test the difference in slope of regression lines representing several tests

Tests Compared	t Score	Level of Significance
1 and 2	.0014	NS*
2 and 3	.0041	NS*
4 and 5	.0030	NS*

*At .05 level.

The regression lines tested have been drawn in on Figures 4 and 5. Although the scale is too small in these figures to portray the picture accurately, it can be seen that slopes of the lines representing Tests 1 and 2 are very much parallel. The lines representing Tests 2 and 3 and Tests 4 and 5 are less parallel, but as shown in Table 5, the t-values are very low and do not come close to the t-value of approximately 1.68 that would be needed for significance at the .05 level. Therefore, the null hypothesis that $B_1 - B_2 = 0$ was sustained, and the directional hypothesis was rejected.

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[1] It should be noted that comparisons of Tests 1 and 2 and Tests 4 and 5 did not fully meet all assumptions for the t-test used in that these comparisons contained both independent and correlated data. The Test 2-Test 3 comparison did meet this assumption in that no subject received both Test 2 and Test 3. However, since t scores obtained did not come close to the specified level of significance, no further analysis was deemed necessary.

Interpretations and Conclusions

Performance of Testing Instruments

There was concern as to whether or not this stimulus pattern would work satisfactorily in a simulated classroom situation, and not in a laboratory situation as had been previously used, and if subjects throughout the age range would be able to perform satisfactorily under the experimental conditions imposed.

In the Series A tests mean scores were 1.88 for Test 1, 2.24 for Test 2, and 2.50 for Test 3. Scores were less than expected on Tests 1 and 2. However, the highest score was well within the range of 2.19 to 2.84 bits that had been obtained in similar tests (Table 1). In fact, the mean score of 2.58 obtained for the 20-29 age group on Test 3 in this experiment (group nearest age of subjects in previous tests) was only .10 bits from the mean of the four tests listed in Table 1. If the 1966 test by Garner where he was experimenting with very limited duration times is eliminated from the average, the mean of the three remaining tests was 2.57 bits, no different from the 2.58 obtained by the 20-29-year-olds on Test 3 of this experiment.

In the one previous experiment using the dot and grid pattern, Klemmer and Frick had obtained a mean score of 3.9 bits for the 4 x 4 matrix and a mean score of 4.4 when using the 6 x 6 matrix. Mean scores obtained in this experiment were 3.77 bits with the 4 x 4 matrix and 4.33 with the 6 x 6 matrix, which were slightly lower than the results obtained in the earlier study. However, when the scores of the 20-29-year-olds in this study (the age group most nearly the age of the undergraduate students used as subjects by Klemmer and Frick) are compared with the earlier study, there is very little difference: 3.9 to 3.91 and 4.4 to 4.31.

All subjects were able to perform the experimental task and there was no evidence of practice or fatigue effects greatly influencing the results.

Tests of Hypotheses

It is believed the data provide reasonably good measure of information processing capacity (Hypotheses 1 and 2). As shown in Figures 4 and 5, there was a decline with age in all tests, as predicted, with a statistically-significant decline in three of the five tests. Sub-group variations from the general trend could be attributed to sampling error.

The most interesting phenomena in the study was the Test 3 results, when analyzed in terms of the independent variable. It was predicted (Hypothesis 1) that as age increased performance would decrease. This did not happen ($p > .05$, Table 3). Also, it was predicted that in this more complex discrimination situation older subjects would have more difficulty, relatively, making the judgments called for than they would where coarser discriminations were called for (Tests 1 and 2) in the unidimensional stimulus situation. In fact, it would not have been surprising if the line representing Test 3 scores at the older age end of the range in Figure 4 would have dropped below the line representing Test 2 scores. In other words, the distance between lines representing Tests 2 and 3 were expected to be less at the right side of the graph (if they did not cross and intermingle) than they would at the left side (Hypothesis 4). There was no significant difference ($t = .0041$) in these distances.

These results lend themselves to considerable speculation. It is possible, although considered unlikely, that there is some element from, or net result of, long-term experience that would enable the older subject to perform at a higher level as the complexity of the stimulus condition increases. A more likely explanation would lie in psychological factors. The experimenter was impressed with the dedication with which the subjects went about their tasks in the experimental situation. There was also some evidence that older subjects might have applied themselves more strenuously, or appeared to have been more concerned with a high level of performance, although the subjects were not aware that age was one of the variables being studied. On the other side, there is a strong possibility that the older subjects entered the test situation at a higher stress or anxiety level than did the younger subjects. Researchers at the Duke University Center for the Study of Aging discovered that older subjects entered a short learning-testing situation (40 minutes) at a higher anxiety level than did younger subjects, and with the older subjects the anxiety level continued to increase through the test period, while for the younger subjects there was an anxiety leveling off or reduction starting about 10-12 minutes into the test situation. Then, for the older subjects the anxiety level started to go down some 10-15 minutes after the test was completed.[1] It is possible that the older subjects in this study reached the point of anxiety reduction during the second test.

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[1] A. H. Powell, Jr., <u>et al</u>., "Physiologic Response Patterns Observed in a Learning Task," <u>Archives of General Psychiatry</u>, Vol. 10 (Feb., 1964), pp. 120-123.

In the Crossman and Szafran cardsorting studies, reported earlier, it should be recalled that the significant differences between 20-25-year-olds and 70-80-year-olds appeared in what the authors called the initial rate, and not the incremental rate.[1]

It is quite possible that Tests 3 and 5 are more representative of older-age abilities than are Tests 1, 2, and 4.

Related to this discussion is the question of individual variations. The standard deviation and range of residuals (range of variation of individual scores from predicted scores) should give reliable figures on this question (Table 6). The greatest amount of variation of individual test scores from the group means was expected for the most complex tests--Tests 3 and 5. In the judgments of sizes of squares this was not the case. In fact, just the opposite occurred. There was greater individual variation in Test 1 than in Test 2 and in Test 2 than in Test 3. It appears significant that the standard deviation of .26 for Test 2 was .02 greater than the standard deviation of Test 3, while the standard deviation of Test 1, at .32, was .06 greater than for Test 2. (In all situations either 2 or 3 was the second test.) Individual performance on Tests 4 and 5 was as expected, with greater deviation on the more complex test. This further substantiates the idea proposed on the previous page that it took at least some of the older subjects longer to get "warmed up" and performing at a high level, or to reach their peak performance period.

Table 6. Standard deviations and range of residuals for five tests

Test	Standard Deviation	Range of Residuals
1	.32	1.591
2	.26	1.050
3	.24	0.961
4	.19	0.618
5	.30	1.110

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[1] Crossman and Szafran, op. cit., pp. 129-132.

Performance on Test 2 was not as had been expected. However, the subjects assigned to Test 3 were apparently higher performers as a group than the subjects assigned to Test 2. Figure 7 shows the combined Test 1 scores for the two test groups assigned to Test 2 (Groups 1 and 2) and the two test groups assigned to Test 3 (Groups 3 and 4). As the chart graphically illustrates, the Test 3 subjects outperformed the Test 2 subjects on Test 1 at all age levels.

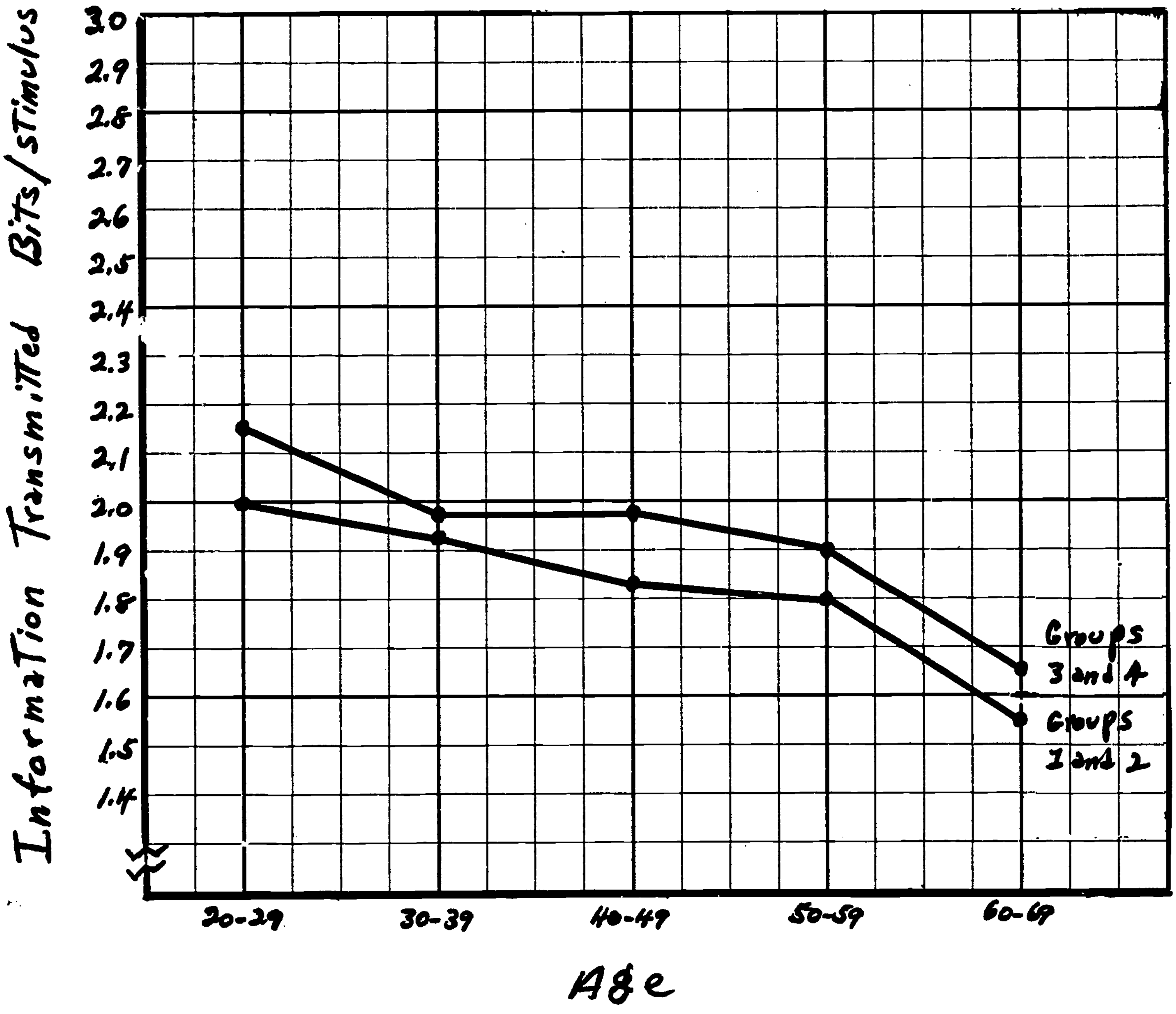

Fig. 7. A comparison of group scores on Test 1, Groups 1 and 2 combined and Groups 3 and 4 combined.

Suggestions for Additional Research

This exploratory study has demonstrated the feasibility of using perceptual judgments and visual stimuli in a group setting with a continuous variable--age in this instance. It is felt that the greatest contribution of this experiment has been to test these particular experimental methods and hopefully point the way for additional research on important theoretical and practical problems in adult education. It is suggested that the following seven areas would be fruitful ones for additional research.

(1) Channel Capacity.--With a wider stimulus range, channel capacity could be more fully explored. Although approaching the limits of channel capacity, this study did not contain enough stimulus categories to fully determine this point, at least not to the extent that a continuous independent variable could be fully evaluated. To do this it is necessary to have enough discrimination levels to reach the point where the channel capacity curve has reached a peak and has curved downward again. Using the size of squares stimulus, this would probably require stimulus presentations with the following amounts of stimulus uncertainty: 3.0, 3.5, 4.0, 4.5, 5.0, and 5.5 bits.

A similar experiment could be developed using a multidimensional stimulus presentation, although caution must be exercised to assure that stimuli used are suitable across the age range. Perhaps some combination of size and shape or angle could be developed that would be more suitable than the dot placement used in this study.

(2) Relationships to other factors.--A highly-educated population was purposely selected for this study since the desire was to control for extraneous variables such as amount of schooling, education, and current use of learning powers. But much of adult education today is concerned with individuals with below-normal intelligence, a low level of formal education, and with a considerable time lapse since they were in formal educational situations. It would appear most interesting to explore the relationship of information processing capacity and channel capacity to some of these important factors.

(3) Effects of time.--Some of the more interesting aspects of studies of adult learning have revolved around the time aspect--the phenomena of the older individual requiring more time to perform a particular learning task. Recent perceptual discrimination studies with absolute judgments have noted the effects of duration time on performance. A particularly interesting

study could be developed, with both unidimensional and multidimensional stimuli, to explore further the time factor and bring in age as a second independent variable.

(4) Anxiety and stress levels.--There is an indication in this study that younger subjects reached a peak level of performance in less time than did older subjects. Exploration of this idea could provide some interesting data to supplement work now going on by medical researchers and psychologists studying the effects of anxiety on adult learning. Also, more information here could contribute to classroom practice if teachers were more aware of human limitations. For example, one principle of teaching adults is that a certain stress level is needed to insure top performance, but the teacher must be careful to hold anxiety within reasonable bounds. These boundaries have not been defined.[1]

(5) Stimulus enrichment.--Another study that might be developed, with practical application, is the idea of stimulus enrichment, explored to some extent in the instrumentation phase of this study. Such a study would be exploratory, but would be well worth pursuing.

(6) Stimulus combinations.--A limited amount of work has been done with stimulus combinations, such as visual and auditory. Today the teacher of adults is faced with a wide variety of methods and techniques that might be chosen for classroom use. A study of perceptual judgments combining auditory and visual stimuli might be fruitful.

(7) Sex differences.--One of the surprises of this study was the significant difference in the performance of males and females. This biological factor, and probably others, would be worth exploring further since the adult classroom is usually composed of representatives of both sex.

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[1] A followup study, titled "The influence of stress and anxiety on adult performance as related to time and varying levels of stimulus complexity," has been proposed to further investigate this area. If funded, this study will be conducted during the latter half of 1968.

Summary

Research has proven that older people can learn, although there is a decline in certain kinds of learning abilities. With increasing emphasis on programs for middle-age and older adults, there is need for new approaches to the study of the human organism to determine its various capacities for learning and performance.

A mathematical model developed from information theory has provided a tool useful in measuring certain human characteristics, specifically the information processing capacity of the human organism when it is considered as a communication system. In this exploratory study the use of absolute judgments to measure judgmental discrimination accuracy and information processing capacity was extended to measure subjects over a 45-year age range and under simulated classroom conditions. Using visual stimuli, 74 subjects judged size of dark squares on a light background in three tests and the location of the placement of a dot in a grid pattern in two tests. The subjects, college graduates and equally divided by sex, ranged in age from 23 to 68.

Specifically the study sought to determine if there is a change in information processing and channel capacity as the human organism grows older, and if this relationship is altered with a change in stimulus complexity and dimensionality of the stimulus presented.

As theoretical background for the study the work of a number of well-known psychologists, educators and gerontologists was reviewed. Out of this framework came the hypotheses that both information processing capacity and information channel capacity would decline as the human organism aged; that this decline would be more pronounced as the complexity of the stimulus presentation increased; but all subjects would exhibit higher performance as the number of dimensions on which judgments were made was increased from one (size of squares) to two (dot in grid pattern).

The stimuli, presented to the subjects in four groups ranging in number from 17 to 20, were reproduced on slides and projected onto a screen with duration time tachistoscopically controlled. Each subject was exposed to three of the five tests presented. Although working under severe time restrictions, in most respects this presentation in a simulated classroom situation resulted in performance as expected. Information-transmitted scores obtained were in line with scores obtained in similar tests where single subjects performed in a laboratory situation.

As predicted, performance declined as age increased. In three of the five tests this decline was statistically significant (.05 level); in the other two tests the decline was in the predicted direction. But, contrary to prediction, the three tests where the results were statistically significant were the ones containing the least complex stimulus situation. It was speculated that older subjects approached the test situation with a higher level of anxiety than did the younger subjects. Since the least complex tests were presented first, it was assumed that this high-anxiety state masked the performance of older subjects in the earlier tests, but as this state faded out older subjects reached their peak performance which was very little if any below that of the younger subjects.

Subjects at all ages scored significantly higher on the multidimensional stimulus presentations (dot and grid) than they did on the unidimensional stimulus presentations (size of squares).

The instruments did not perform precisely enough to fully develop scores for channel capacity within the two series of tests (squares and dot pattern), but between series it could be stated that channel capacity was greater at all ages when the multidimensional stimulus was used.

There was a sex difference in performance, with the males outscoring the females in all tests. Eye condition, location in the testing room, and interaction between the several variables considered did not influence the results.

This study pointed the way for additional research, specifically investigations to determine channel capacity more accurately; the relationship of information processing capacity to such factors as intelligence, amount of education, and sex; the effects of time on performance; and stimulus enrichment and combinations.

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Appendix A - Data and Sample Response Sheets

Research Study: 1967 ABE Institute, Florida State University

Group____________ Age____________ Sex: Male_____ Female_____

Amount of Schooling: High School_____ 1-2 years college_____

3-4 years college_____ College graduate_____ Graduate work_____

Testing room location: 1st row____ 2nd row____ 3rd row____ 4th row____

In recent years there has been a large number of psychological experiments to determine various capacities of children. Considerable study has been given to the golden age (over 65) group, but very little attention has been given to the age range of the adults that participate most in adult education. As we expand our educational programs and develop new teaching techniques and devices, it is important that we learn more about the various sensory capacities of these adult students. This research project in perceptual visual discrimination is designed to contribute a part of this much needed knowledge.

In this study you are being asked to make judgments of rather common and familiar stimuli--size relationships of dark squares on a light background, and location of a black dot in a grid pattern on a light background. You are urged to do your best at all times. Your contribution to this important study will be greatly appreciated.

Your ability to make these judgments may hinge in part on your eye condition or seeing ability. Considering your age, how would you rate your eyesight?

Good_______ Average_______ Poor_______

If you wear glasses, do you feel that you need new glasses?

Yes________ No________

If you do not wear glasses, do you feel that you need glasses?

Yes________ No________

Do you have any eye problems that have not been corrected through your use of glasses, or that could not be corrected by the use of glasses? Yes________ No________

If yes, please explain____

____

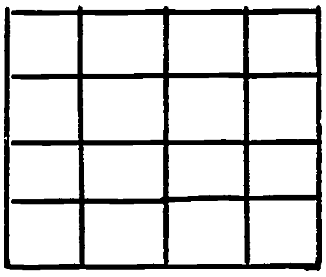
Do you now have any temporary visual difficulty (eye injury, foreign matter in eye, etc)? Yes________ No________

If yes, please explain____

Test 1 Page 1

1	1	2	3	4	5	6	7	8
2	1	2	3	4	5	6	7	8
3	1	2	3	4	5	6	7	8
4	1	2	3	4	5	6	7	8
5	1	2	3	4	5	6	7	8
6	1	2	3	4	5	6	7	8
7	1	2	3	4	5	6	7	8
8	1	2	3	4	5	6	7	8
9	1	2	3	4	5	6	7	8
10	1	2	3	4	5	6	7	8
11	1	2	3	4	5	6	7	8
12	1	2	3	4	5	6	7	8
13	1	2	3	4	5	6	7	8
14	1	2	3	4	5	6	7	8
15	1	2	3	4	5	6	7	8
16	1	2	3	4	5	6	7	8
17	1	2	3	4	5	6	7	8

Test 4 Page 1



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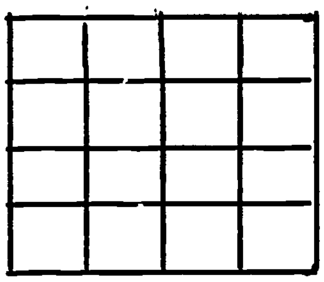

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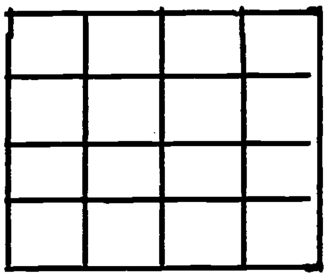

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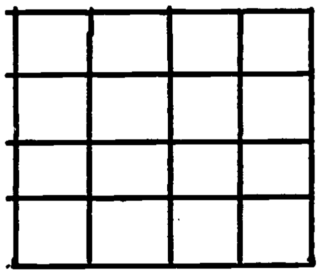

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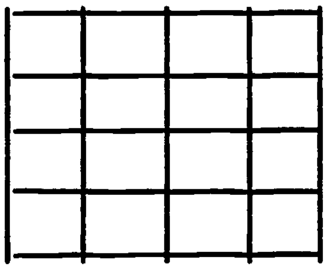

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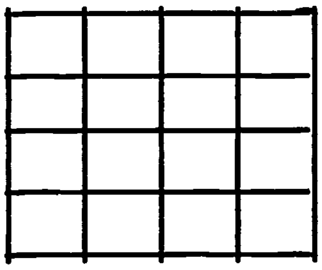

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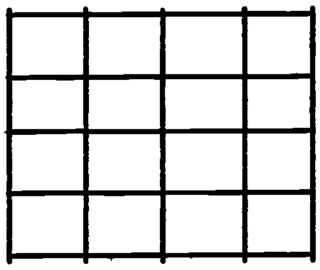

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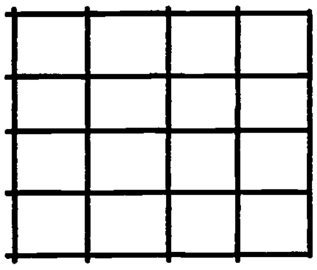

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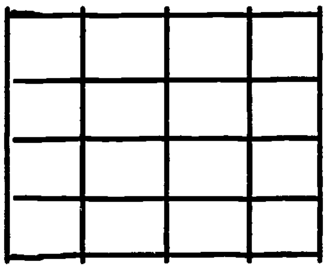

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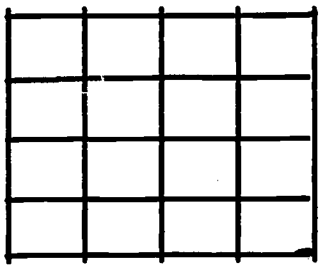

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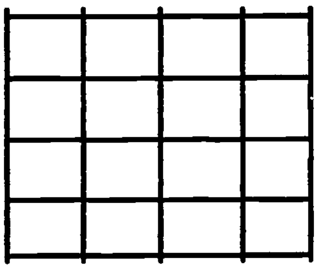

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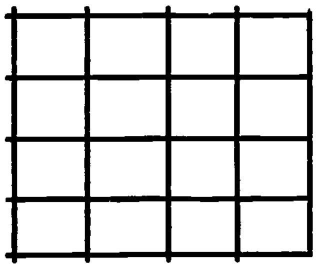

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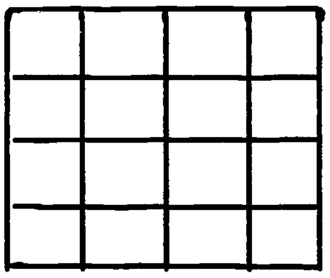

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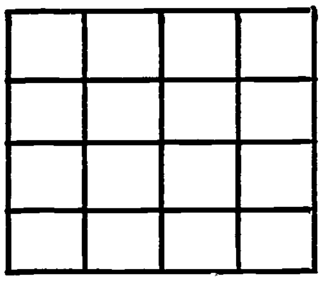

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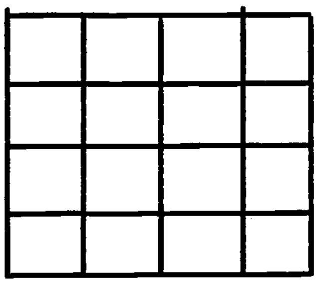

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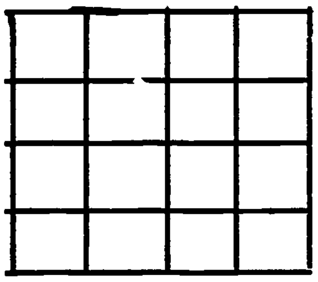

16

Appendix B - Matrices Used for Statistical Analysis

Test 1 Subject ______

	1	2	3	4	5	6	7	8	Freq.	Wts.
1										
2										
3										
4										
5										
6										
7										
8										

U_{max} = 3.00 + ____.____ = ____.____

(1) .132 x ______ = ____.____

(2) .216 x ______ = ____.____

(3) .280 x ______ = ____.____

(4) .332 x ______ = ____.____

(5) .375 x ______ = ____.____

____.____

U_t = ____.____ - ____.____ = $\boxed{\_\_\_\_.\_\_\_\_}$

Test 2

Subject ________________

	1	2	3	4	5	6	7	8	9	10	11	12	13
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													

(1) .090 x ________ = ____.____

(2) .155 x ________ = ____.____

(3) .204 x ________ = ____.____

(4) .246 x ________ = ____.____

(5) .285 x ________ = ____.____

(6) .318 x ________ = ____.____

(7) .347 x ________ = ____.____

(8) .373 x ________ = ____.____

(9) .396 x ________ = ____.____

(10) .416 x ________ = ____.____

____.____

U_{max} = 3.70 ____.____ = ____.____

(1) .090 x ______ = ____.____

(2) .155 x ______ = ____.____

(3) .204 x ______ = ____.____

(4) .246 x ______ = ____.____

(5) .285 x ______ = ____.____

______.______

U_t = ____.____ - ____.____ = $\boxed{\_\_\_\_.\_\_\_\_}$

Appendix C - Individual Test Scores

INDIVIDUAL TEST SCORES FOR ALL TESTS BY TEST GROUP, AGE, AND SEX

Subject Number	Age	Sex	Tests				
			1	2	3	4	5
			Test Group 1				
1	23	F	2.27	2.30		4.00	
2	26	F	2.09	2.57		4.00	
3	32	M	2.23	2.56		3.96	
4	33	M	2.04	2.52		3.62	
5	37	M	2.01	2.49		4.00	
6	39	F	1.45	2.32		3.86	
7	42	M	2.07	2.48		3.90	
8	43	M	2.16	2.57		3.88	
9	46	M	2.20	2.61		3.96	
10	47	F	1.53	1.92		3.69	
11	49	F	1.89	2.20		3.56	
12	50	F	1.42	2.14		3.81	
13	50	F	1.48	2.00		3.96	
14	51	F	1.88	2.28		3.73	
15	52	F	1.80	1.94		3.52	
16	57	F	1.82	2.35		3.70	
17	60	F	1.47	1.90		3.49	
18	60	F	1.64	2.01		3.46	
19	62	F	0.63	1.86		3.49	

Subject Number	Age	Sex	Tests 1	2	3	4	5
			Test Group 2				
21	25	F	2.03	2.07			4.44
22	28	F	1.58	2.01			3.97
23	30	M	2.08	2.57			4.21
24	31	F	1.91	2.11			4.17
25	32	M	2.03	2.45			4.71
26	33	M	1.83	2.70			4.92
27	34	M	1.85	2.27			4.54
28	36	M	1.93	2.37			4.15
29	37	F	1.93	2.23			4.53
30	41	F	1.98	2.18			4.35
31	42	M	1.68	2.23			4.57
32	46	M	1.62	2.20			4.09
33	46	F	1.43	1.56			3.92
34	52	F	1.96	2.48			4.30
35	53	M	2.23	2.29			4.27
36	56	M	1.85	1.86			4.49
37	62	M	1.92	2.24			3.85
38	68	F	2.03	2.18			4.34

Subject Number	Age	Sex	Tests 1	2	3	4	5
			Test Group 3				
41	25	F	2.21		2.64	3.73	
42	33	M	2.00		2.57	3.80	
43	35	F	2.05		2.38	3.90	
44	36	M	2.02		2.62	3.51	
45	37	M	2.15		2.84	3.70	
46	38	F	2.00		2.60	4.00	
47	43	M	2.25		2.74	3.96	
48	45	F	1.96		2.82	3.81	
49	46	M	1.85		2.54	4.00	
50	47	M	1.83		2.34	3.76	
51	50	F	1.08		2.14	3.43	
52	53	M	2.31		2.96	4.00	
53	58	F	2.15		2.57	3.86	
54	61	M	1.56		2.66	3.76	
55	62	M	1.39		2.44	3.64	
56	62	M	1.77		2.31	3.88	
57	67	M	1.82		2.57	3.45	

Subject Number	Age	Sex	Tests				
			1	2	3	4	5
			Test Group 4				
61	27	M	----		2.49		4.12
62	29	M	2.08		2.67		4.72
63	32	F	2.32		2.54		4.47
64	33	F	1.86		2.58		4.18
65	34	F	1.77		2.15		3.98
66	35	M	2.04		2.80		4.88
67	36	M	2.14		2.52		4.97
68	36	M	2.09		2.59		3.86
69	36	F	1.51		2.36		4.23
70	37	F	2.42		2.45		4.32
71	38	F	1.76		2.23		4.32
72	38	F	1.17		2.09		4.00
73	39	M	2.12		2.84		4.64
74	39	F	2.11		2.34		4.35
75	47	M	----		2.41		4.72
76	52	M	1.57		2.29		3.79
77	53	F	1.84		2.17		4.39
78	55	M	2.14		2.54		4.57
79	56	F	2.19		2.88		4.13
80	57	M	----		1.99		4.33

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